

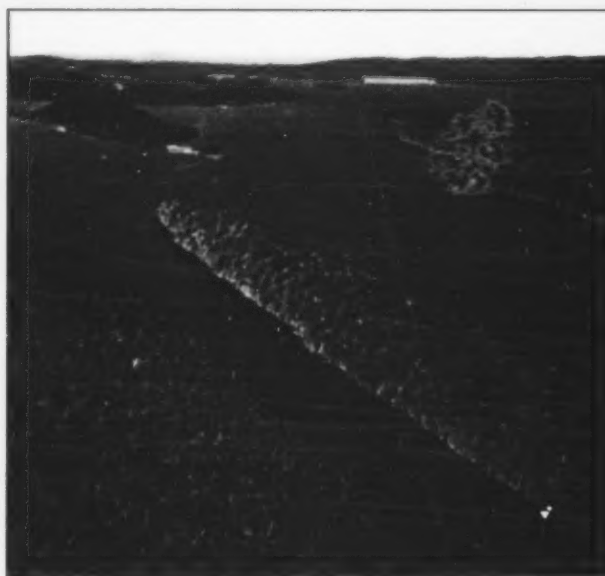
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TILL GEOCHEMISTRY OF SOUTHWESTERN NEW BRUNSWICK



S. Allard, A.A. Seaman,
A.G. Pronk, and G.R. Boldon

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Cover illustration: *Submerged megaflutes at Spednic Lake, southwestern New Brunswick, showing glaciated terrain typical of the Maguadavic Highlands.*

Photograph courtesy of Martin Marshall,
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ABSTRACT

Between 1990 and 2003, 2122 basal till samples were collected in southwestern New Brunswick and subjected to geochemical analysis using a variety of laboratories and analytical techniques. The resulting data set (26 elements) underwent a comprehensive levelling procedure before being compiled into regional-scale till geochemical contour maps. Multivariate-element-association contour maps were plotted for indicators of precious-metal mineralization, base-metal mineralization, tin–tungsten mineralization, nickel–cobalt–copper mineralization, rare-metal mineralization, and rare-earth element concentration. Individual-element contour maps were plotted for As, Ba, Co, Cr, Cs, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Rb, Sb, Th, U, W, and Zn. When overlain on regional bedrock geology maps, these contour maps effectively highlight areas of potential mineralization at a regional scale and facilitate comparison of the magnitude of anomalies across the report area.

RÉSUMÉ

Des données géochimiques nivelées (26 éléments) tirées d'échantillons de till de fond prélevés dans le sud-ouest du Nouveau-Brunswick (1990–2003) sont fournies. Des cartes en courbes de niveau d'associations d'éléments multiples faisant état des indicateurs de minéralisation de métaux précieux, des indicateurs de minéralisation de métaux communs, des indicateurs de minéralisation d'étain–tungstène, des indicateurs de minéralisation de nickel–cobalt–cuivre, des indicateurs de minéralisation de pegmatite à métaux rares et des éléments de terres rares, sont offertes. Des cartes en courbes de niveau individuelles visant l'As, le Ba, le Co, le Cr, le Cs, le Cu, le Fe, le Hg, le Mn, le Mo, le Ni, le Pb, le Rb, le Sb, le Th, l'U, le W et le Zn, sont offertes. Ces cartes en courbe de niveau qui recouvrent la géologie du substrat rocheux régional servent à mettre en relief les secteurs de minéralisation prometteurs à une échelle régionale et permettent une comparaison de la magnitude des anomalies dans différentes parties de la région.

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INTRODUCTION

In New Brunswick, approximately 90% of the land surface is covered with unconsolidated materials that were either deposited directly by the action of Wisconsin glaciers or derived from wasting of the ice masses (Pronk and Ruitenberg 1991). A comprehensive understanding of these unconsolidated materials is important to a number of applications including mineral exploration, forestry, agriculture, and land-use planning.

The current report describes an ongoing till geochemistry program being conducted in southwestern New Brunswick (Fig. 1) by the New Brunswick Department of Natural Resources (NBDNR). The program began in 1990 and has substantially increased the knowledge base of surficial geology in the province. The primary objective of the program is to identify new mineral exploration targets. Subsidiary objectives are to 1) assess baseline till geochemistry, 2) categorize till on the basis of features such as grain size, lithology, colour, and compactness for the future production of multipurpose surface materials maps (see Pronk et al. 2005), and 3) delineate the glacial transport trajectories in this area of complex ice-flow history.

Basal till is the most common glacial sediment used for drift prospecting and is the focus of this investigation, although ablation till samples were collected where basal till was unavailable. By the end of the 2003 field season, 2568 till samples had been collected from the 21 G and 21 J map areas (Fig. 1). Of these samples, 2122 are basal tills comprising lodgement till, basal melt-out till, and/or deformation till, as classified by Brodzikowski and Van Loon (1987). Seaman (2001a) and Allard (2003) provide a complete description of the sampling methodology.

The 2568 till samples were subjected to geochemical, granulometric, and lithological analyses. Geochemical analyses were performed using Instrumental Neutron Activation Analysis (INAA), Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (partial data set), Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (partial data set), and Atomic Absorption Spectrometry (AAS) (partial data set) on the < 63 μm fraction of each sample. Granulometric analysis was conducted on the < 2 mm fraction, and lithological analysis was conducted on the 2 cm to 10 cm fraction.

The data set for the 2122 basal till samples was compiled into a series of regional-scale till geochemical contour maps that depict either multivariate-element-association plots or single-element plots. To create the maps, data for 26 elements (As, Au, Ba, Ce, Co, Cr, Cs, Cu, Eu, Fe, Hg, La, Lu, Mn, Mo, Ni, Pb, Rb, Sb, Sm, Tb, Th, U, Yb, W, and Zn) were subjected to a comprehensive levelling procedure. The current report presents the contour maps, interprets specific multivariate-element anomaly patterns, and identifies potential target areas for follow-up exploration.

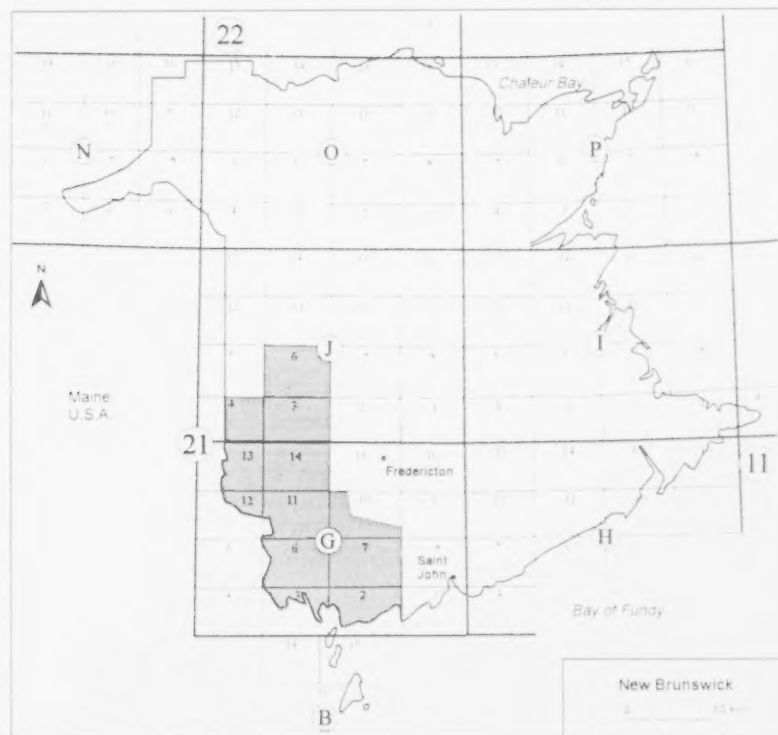


Figure 1. Location of report area in southwestern New Brunswick, showing NTS map sheets.

LOCATION AND ACCESS

The report area comprises parts of twelve 1:50 000 NTS map sheets in southwestern New Brunswick (Fig. 1, Table 1). It is confined on the west by the Canada–U.S.A border with the State of Maine and on the south by the Bay of Fundy (Fig. 2). Notable communities in the district include Woodstock, McAdam, St. Stephen, St. Andrews, and St. George. Much of the region has a low population density. The New Brunswick capital city of Fredericton and the active seaport of Saint John are both located near the report area (Fig. 2).

The northern part of the report area is transected by the Trans-Canada Highway (No. 2) and the southernmost part by Highway No. 1 (Fig. 2). Many secondary highways, plus a network of logging and other private roads, also intersect the area. Where no roadway exists, access can be gained by footpaths, cutlines, transmission corridors, railroads, and the Maritimes–Northeast Pipeline route.

Past-producing mines are situated 30 km north of St. George at Mount Pleasant (Sn, W) and 20 km west of Fredericton at Lake George (Sb) (Fig. 2). Recent gold discoveries near Clarence Stream in the Rollindam map area (NTS 21 G/06) and near Poplar Mountain in the Forest City map area (21 G/12) have renewed exploration interest in this part of the province (Fig. 1, 2).

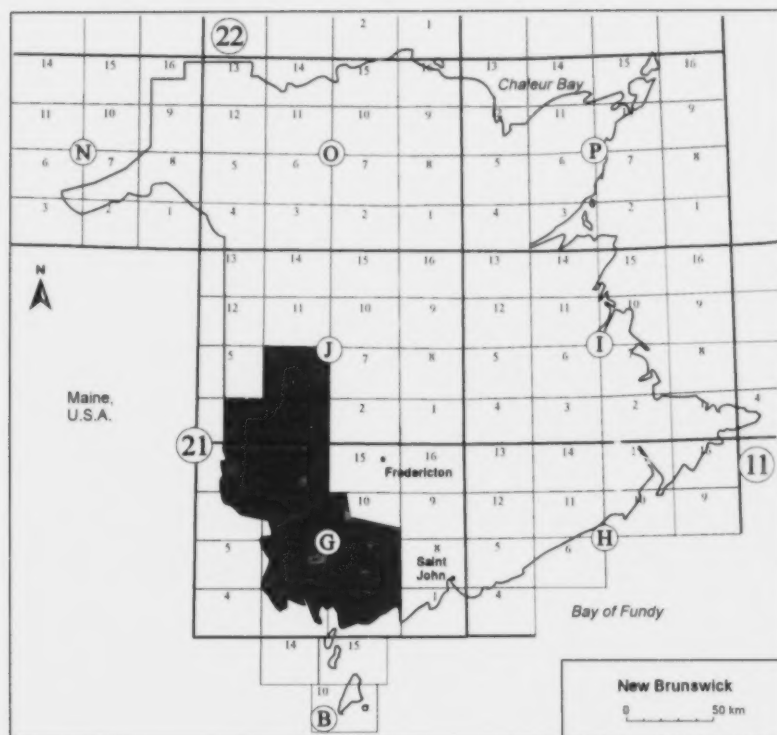


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Table 1. Till geochemical data for southwestern New Brunswick.

* Partial data set.

Map Sheet (1:50000)	NTS #	Sampling Year	Reference Source	Method	Laboratory	Digestion
St. George	21 G/02	2003	Pronk et al. (2004)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
St. Stephen	21 G/03	2002	Pronk et al. (2003a)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
Rollingdam	21 G/06	2001	Allard (2003) Pronk et al. (2002)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
McDougall Lake	21 G/07	2000, 2001	Pronk et al. (2002)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
Fredericton Junction	21 G/10	2002	Pronk et al. (2003b)	ICP-MS	ACME	aqua regia
				INAA	Becquerel	n/a
McAdam	21 G/11	1991, 1992 1993, 1994	Stumpf (1995) Seaman (2003a)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	aqua regia
Forest City	21 G/12	1990	Seaman (1992, 1993b, 1999a)	INAA	ACTLABS	n/a
				AAS*	DNR	aqua regia
Fosterville	21 G/13	1990, 1992 1993	Seaman (1993a, 1994, 1999a)	INAA	ACTLABS	n/a
				ICP-OES*	ACTLABS	aqua regia
				AAS*	DNR	aqua regia
Canterbury	21 G/14	1990, 1991 1995	Balzer (1992) Seaman (in press)	INAA	ACTLABS	n/a
				ICP-OES*	ACTLABS	four-acid
				AAS*	DNR	aqua regia
Millville	21 J/03	1995, 1996 1997, 1998	Seaman (1999b, c)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	four-acid
Woodstock	21 J/04	1999	Seaman (2000)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	four-acid
Coldstream	21 J/06	1998, 2000 2001, 2002	Seaman (2001, 2002, 2003b)	INAA	ACTLABS	n/a
				ICP-OES	ACTLABS	four-acid

PHYSIOGRAPHIC SETTING

The report area lies primarily within the New Brunswick Highlands of Bostock (1970), which Rampton et al. (1984) separated into three physiographic divisions: the St. Croix, Miramichi, and Caledonian (more recently referred to as Caledonia) highlands. Most of the area is situated in the St. Croix Highlands and the Miramichi Highlands (Fig. 3).

As well, parts of the Woodstock (21 J/04), Coldstream (21 J/06), and Millville (21 J/03) map areas are located in the Chaleur Uplands physiographic division, and parts of the McAdam (21 G/11) and Fredericton Junction (21 G/10) map areas lie within the New Brunswick Lowlands physiographic division (Rampton et al. 1984; Fig. 1, 3).

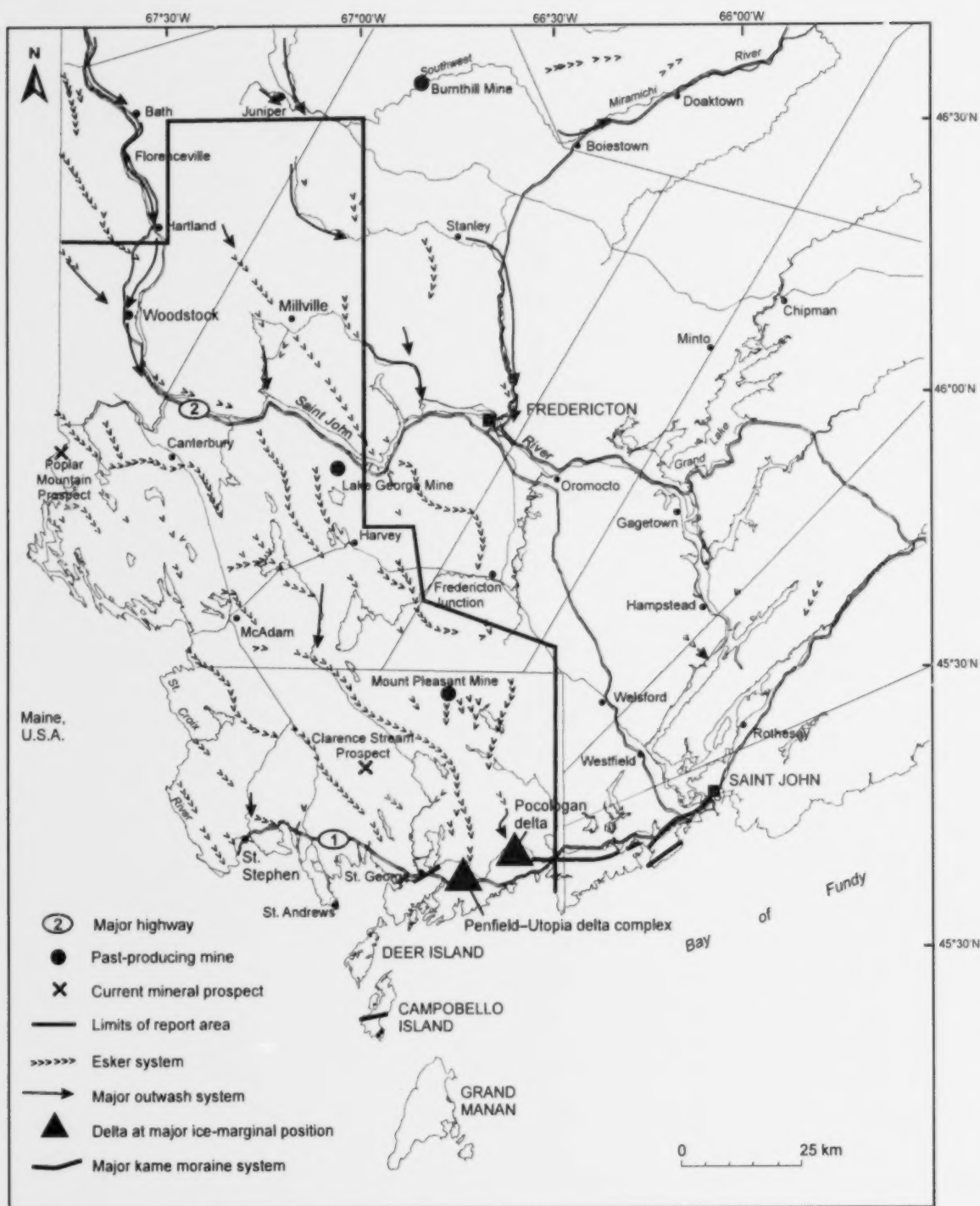


Figure 2. Selected past-producing mines and current mineral prospects in the report area. Map also shows general infrastructure and distribution of major eskers and ice marginal positions in southwestern Brunswick.

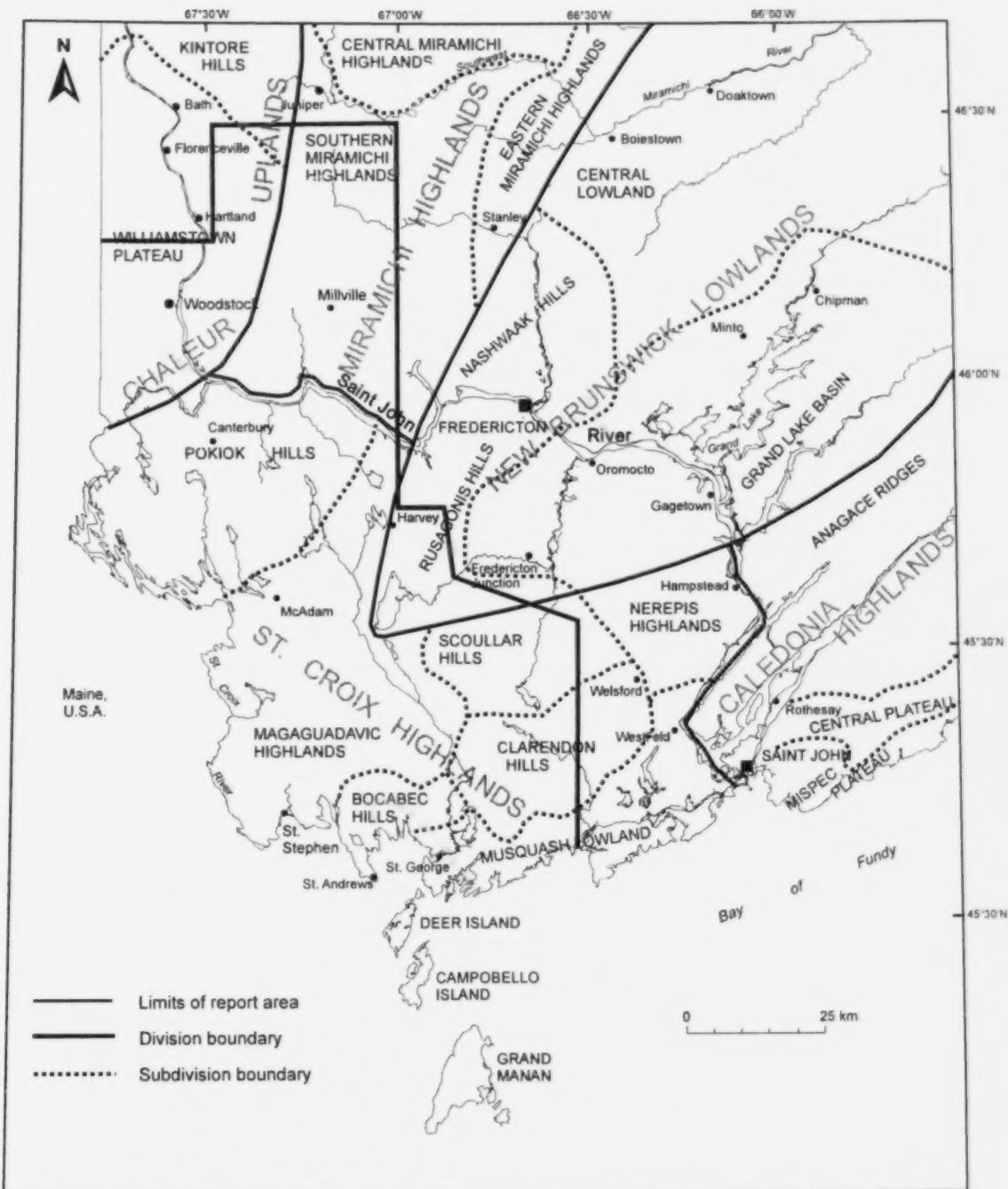


Figure 3. Physiography of southwestern New Brunswick, modified from Rampton et al. (1984). The Caledonia, St. Croix, and Miramichi highlands together represent the New Brunswick Highlands of Bostock (1970).

St. Croix Highlands

The St. Croix Highlands cover much of southwestern New Brunswick (Fig. 3). They are bound by the easterly flowing section of the Saint John River west of Fredericton and the southerly flowing section of the same river north of Saint John (Rampton et al. 1984). The St. Croix Highlands are elevated relative to the Bay of Fundy to the south and the New Brunswick Lowlands to the northeast (Fig. 3). Within the report area, the St. Croix Highlands achieve maximum elevations of between 300 m and 350 m (Rampton et al. 1984). Local relief ranges from tens of metres up to 150 m or more in some localities.

Much of this division, namely the Magaquadavic Highlands subdivision, typically consists of an undulating ridge-and-valley terrain. Ridges tend to be streamlined into megaflutes aligned northwest-southeast, reflecting the high degree of glacial erosion characterizing this part of the province. Parallel drainage patterns are common as most major rivers, secondary streams, and tertiary streams are constricted by the ridges. In poorly drained broad depressions, the drainage pattern is deranged (Rampton et al. 1984).

Miramichi Highlands

The report area encompasses only the southern part of the Miramichi Highlands (Fig. 3). This region of rolling hills and broad depressions features local relief averaging 60 m to 90 m. Maximum elevations here range from 300 m to 350 m. The area typically is well drained and characterized by an irregular dendritic drainage pattern (Rampton et al. 1984).

Chaleur Uplands

The Chaleur Uplands (Fig. 3) form a plateau that locally is dissected by major streams and interrupted by clusters of hills. The uplands comprise several subdivisions, two of which lie within the report area: the Williamstown Plateau and the Kintore Hills (Rampton et al. 1984).

The Williamstown Plateau (Fig. 3) is lower in elevation than the adjacent Miramichi Highlands and consists of gently rolling hills showing minor relief (30 m to 60 m). Areas of higher relief reach up to 150 m and occur along the deeply incised Saint John River valley and its tributaries. The area predominantly is well drained and exhibits a dendritic drainage pattern, except in valley bottoms and local depressions blocked by glacial sediments.

The report area includes only the southernmost part of the Kintore Hills subdivision, east of Florenceville (Fig. 3). Here, the southern boundary of the subdivision coincides with a bedrock-controlled scarp 150 m to 245 m in height (Rampton et al. 1984). Local relief throughout the Kintore Hills averages 120 m to 200 m, reaching up to 270 m along the Saint John River valley. Because of the substantial relief, much of the area is well drained by a pronounced dendritic drainage pattern.

New Brunswick Lowlands

The area extending from near the Village of Harvey to Fredericton Junction, and encompassing Oromocto Lake, forms part of the Rusagonis Hills subdivision of the New Brunswick Lowlands (Fig. 3). Rolling hills formed by incision of the Saint John River and its tributaries dominate the landscape. Local relief in upland areas tends to be low (10 m to 15 m) but can increase substantially near streams (Rampton 1984 et al.). The elevation of ridges and hills commonly crests near 210 m. The area is well drained except for broad, shallow depressions north of Oromocto Lake. Both dendritic and deranged drainage systems have developed.

GEOLOGICAL SETTING

Bedrock Geology

The bedrock geology of New Brunswick comprises part of the northeastern Appalachian Orogen, which has been divided into several tectonostratigraphic zones based on their unique stratigraphy and deformational history (Fig. 4). Belts of early Paleozoic and older rocks within the orogen are divided into zones reflecting their relative position to, or within, the early Paleozoic Iapetus Ocean (Williams and Hatcher 1982).

Three of these belts — the Avalon, Gander, and Dunnage zones — occur in New Brunswick. Fyffe and Fricker (1987) provide a comprehensive tectonostratigraphic analysis of the province. The Avalon Zone is underlain by Precambrian volcanic rocks of Gondwanan affinity; the Gander Zone is underlain by sedimentary sequences deposited off the Gondwanan continental margin; and the Dunnage Zone is underlain by tracts of Iapetus ocean floor, island arcs, and back-arc basins. Rocks of all three zones were deformed and successively accreted to the Laurentian continental margin during closure of the Iapetus Ocean.

The Avalon Zone in New Brunswick is referred to as the Caledonia Zone (Fig. 5; Fyffe 1994). It is underlain by a Middle Neoproterozoic quartzite-carbonate sequence and a succession of Late Neoproterozoic volcanic and associated intrusive rocks. A Cambrian–Early Ordovician platformal sequence containing distinctive Acado–Baltic trilobite fauna unconformably overlies the Precambrian rocks. The Caledonia Zone is generally considered to represent a fragment rifted from the continental margin of Gondwana during opening of the early Paleozoic Iapetus Ocean.

The Gander Zone in New Brunswick includes the St. Croix and Miramichi zones (Fyffe and Fricker 1987). The St. Croix Zone (Fig. 5) is characterized by Late Cambrian–Middle Ordovician black shale and quartz-rich turbidites that presumably were deposited off the

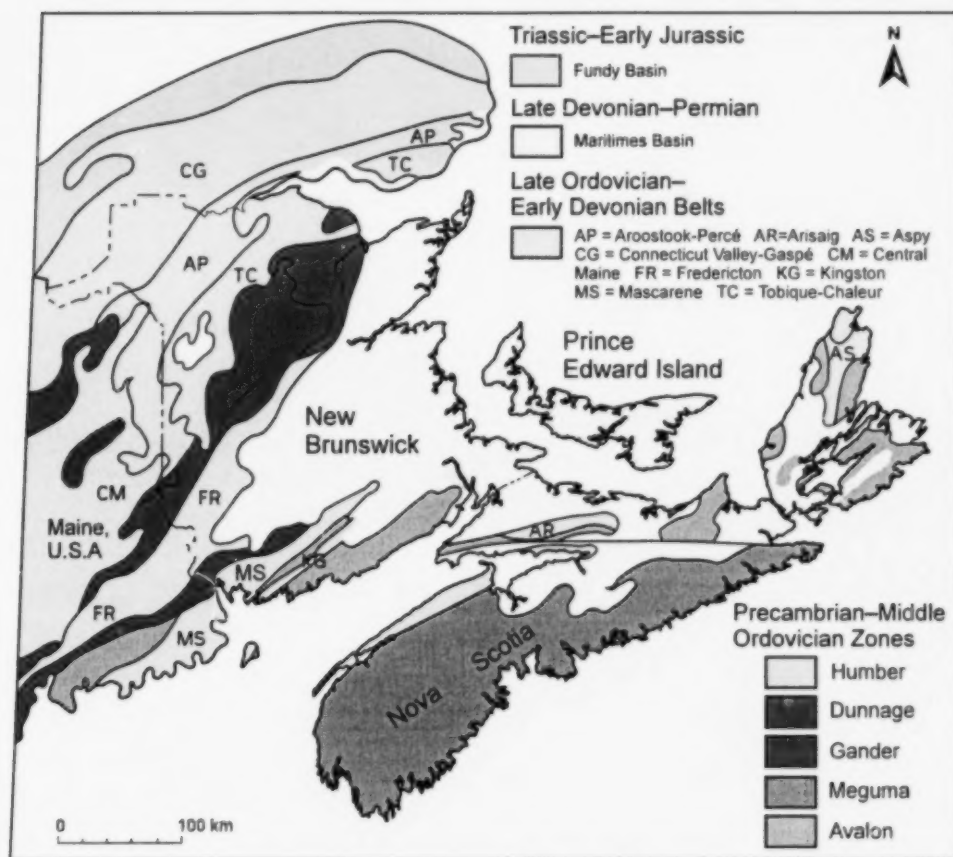


Figure 4. Tectonostratigraphic zones of the northeastern Appalachian Orogen.

Gondwanan continental margin. The Miramichi Zone (Fig. 5) comprises Early-Middle Ordovician volcanic rocks built upon the thick substratum of Late Cambrian-Early Ordovician quartz-rich turbidites.

The Dunnage Zone in New Brunswick is referred to as the Elmtree Zone (Fig. 5; Fyffe and Fricker 1987) and is underlain by an Ordovician ophiolitic suite. Volcanic rocks in the Miramichi and Elmtree zones possess arc and back-arc signatures and are interpreted to have been generated during the Late Ordovician-Silurian contraction of the Iapetus Ocean (van Staal and Fyffe 1991).

New Brunswick also includes belts of Late Ordovician-Early Devonian bedrock developed following closure of the main part of the Iapetus Ocean in the early Paleozoic. These comprise the Restigouche, Fredericton, Tobique-Chaleur, and Mascarene zones (Fig. 5) of Fyffe (1994). The Restigouche and Fredericton zones contain thick successions of calcareous and siliciclastic turbidites that range in age from Late Ordovician to early Devonian. These deep-marine sedimentary sequences likely were deposited in foredeep basins developed in front of the rising nappes during closure of the Iapetus Ocean and subsequent collision of the Gondwanan and Laurentian continental margins.



Figure 5. Geological zonation of New Brunswick.

The Tobique–Chaleur and Mascarene zones are underlain by Silurian–Early Devonian volcanic rocks interbedded with shallow-marine to fluvial sedimentary rocks. The volcanic rocks show intraplate chemical signatures and probably erupted in transcurrent basins that formed as a result of oblique continental convergence. Thickening of continental crust generated bimodal batholithic suites that were emplaced between the Late Silurian and Middle Devonian.

The Maritimes Basin in New Brunswick (Fig. 5) includes Late Devonian–Carboniferous fluvial conglomerate and sandstone sequences, shallow-marine limestone and evaporites, lacustrine oil shales, and subaerial volcanic rocks. These rocks were deposited in a successor basin within the uplifted Appalachian Orogen and are undeformed except along fault zones in southern New Brunswick.

The regional, 1:250 000-scale bedrock geology of the report area is documented by Fyffe (1982) and McLeod et al. (1994). The 1:500 000-scale bedrock geology of the entire province is illustrated on Map NR-1, *Bedrock Geology of New Brunswick* (NBDNRE 2000). Figure 6 is excerpted from Map NR-1 and shows bedrock in the report area; Table 2 lists the bedrock units marked on Figure 6.



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Table 2. Bedrock units in southwestern New Brunswick.

Age	Intrusive Rocks		Stratified Rocks	
	Code	Unit	Code	Unit
Early Jurassic	EJC	Caraquet Dyke		
	EJMI	Ministers Island Dyke		
Late Carboniferous			LCP	Pictou Group
Early Carboniferous			ECMA	Mabou Group
Late Devonian– Early Carboniferous			DCHO	Horton Group
Late Devonian	LDBH	Beech Hill	LDHV LDPI	Harvey Group Piskahegan Group
	LDK	Kedron Stream		
	LDMS	McDougall Brook		
	LDMD	Mount Douglas		
	LDPR	Pleasant Ridge		
	LDSR	Sorrel Ridge		
	LDTR	True Hill		
Early Devonian	EDA	Allandale	EDMS EDT	Mascarene Group Tobique Group
	EDB	Bocabec		
	EDBA	Baring		
	EDBL	Becaguimec Lake		
	EDH	Hawkshaw		
	EDHP	Howard Peak		
	EDHT	Hartfield		
	EDJL	John Lee Brook		
	EDMA	Magaguadavic		
	EDNW	Nashwaak		
	EDPK	Parks Brook		
	EDSL	Skiff Lake		
	EDSS	St. Stephen		
	EDTH	Tower Hill		
	EDU	Utopia		
Late Silurian	LSAB	Allen Brook	LSK LSMS LSPE	Kingsclear Group Mascarene Group Perham Group
	LSCU	Cutler		
	LSEB	East Branch Brook		
	LSFO	Foster Lake		
	LSJL	Jake Lee Mountain		
	LSM	Mohannes		
Early Silurian	ESWBR	West Branch Reservoir	ESK ESMS ESPE	Kingsclear Group Mascarene Group Perham Group
Late Ordovician– Early Silurian			OSMA OSMS	Matapedia Group Mascarene Group
			LOCK LOMD	Cookson Group Meductic Group
Late Ordovician			MÖCK MÖMD	Cookson Group Meductic Group
Middle Ordovician	MÖLC	Little Clearwater Brook	EÖCK EÖMD EÖW	Cookson Group Meductic Group Woodstock Group
Early Ordovician	EÖBT	Benton	EÖCK EÖMD EÖW	Cookson Group Meductic Group Woodstock Group
	EÖGI	Gibson		
Late Cambrian– Early Ordovician			EÖCK EÖTL EÖW	Cookson Group Trousers Lake Metamorphic Suite Woodstock Group
			EEL	
			ESJ	
Cambrian				Saint John Group
Late Neoproterozoic– Middle Cambrian	ZCG	Golden Grove Suite		
Late Neoproterozoic	LZNR	New River Suite	LZC	Coldbrook Group
Early Neoproterozoic			EZGH	Green Head Group



Figure 6. Bedrock geology of southwestern New Brunswick, as excerpted from Map NR-1 (NBDNRE 2000). To ensure optimal use of contour maps in this report, refer to the original Map NR-1, which provides higher quality reproduction of bedrock unit boundaries.

Mineral Deposits

As a result of its complex geological history, New Brunswick contains a wide diversity of mineral deposits. Mining has contributed significantly to the New Brunswick economy since shortly after coal was first exported from Grand Lake in 1643. Metallic mineral deposits were

found later in association with plutons that intruded the various geological zones of the province. Among these deposits were an antimony mine in the Fredericton Zone near Lake George in 1861, a nickel prospect in the St. Croix Zone near St. Stephen in the late 1880s, a tungsten mine along Burnthill Brook in the Miramichi Zone in 1907 (Martin 2003), and a tungsten prospect near Welsford in the Mascarene Zone (Fig. 2, 5) in 1940 (McLeod 1990).

New Brunswick became a major mineral producer following discovery of the volcanic-hosted base-metal sulphide deposits in the Miramichi Zone near Bathurst in 1952. Two years later, tin and tungsten were discovered in the Mount Pleasant volcanic complex along the margin of the Maritimes Basin. Potash was discovered in the Maritimes Basin near Sussex in 1971, tungsten and molybdenum in the Miramichi Zone at Sisson Brook in 1977, and tin at Todd Mountain in 1981 (Ruitenberg and Fyffe 1982; Ruitenberg and McCutcheon 1982; MacLellan et al. 1990).

Gold exploration recently has become the focus of prospectors and junior mining companies operating in southwestern New Brunswick. Significant gold mineralization was discovered in a thrust belt at Cape Spencer in the Caledonia Zone in 1980 (Ruitenberg et al. 1990; Watters 1993), in a subvolcanic stock at Poplar Mountain in the Miramichi Zone in 1994, and at Clarence Stream along the margin of the Saint George Batholith in the Mascarene Zone in 1998 (Chi and Watters 2002; Thorne et al. 2002).

Surficial Geology

Previous Work

Lee (1962) was among the first to systematically map surficial materials in southwestern New Brunswick. Earlier regional soil surveys conducted by Stobbe and Aalund (1944) and Wicklund and Langmaid (1953) provided some information regarding glacial sediments and their relevance to the genesis and physical attributes of overlying soils. More recent works by Gadd (1973) and Rampton and Paradis (1981) describe the composition and extent of surficial materials in the report area and present an interpretation of glacial history.

Rampton et al. (1984) produced a comprehensive overview of the glacial history and surficial geology of New Brunswick, compiling their report from existing data sources, aerial photograph interpretation, and minor supplementary mapping. They revived the "Appalachian system of glaciers" concept of Chalmers (1890) by suggesting that four local ice centres affected New Brunswick during the Wisconsin episode of glaciation. The Laurentide ice sheet may not have penetrated southwestern New Brunswick during the Late Wisconsinan but might have been a driving force behind the New Brunswick glaciers (see Lamothe 1992).

More recently, Seaman (1989a) and Seaman et al. (1993) documented the complexity of New Brunswick's glacial history by conducting an extensive analysis of striated outcrops.

Seaman (1989b, c) and Lamothe (1992) discussed glacial stratigraphy in specific locations within the report area. These studies approximately coincided with detailed fieldwork in the region by the NBDNR, studies that included geochemical surveys performed between 1990 and the present (e.g. Seaman 2002). In light of evidence derived from these recent investigations, it became apparent that some earlier interpretations by Rampton et al. (1984) needed revision. Seaman (2004) addresses these issues and summarizes the current knowledge base of Quaternary geology in New Brunswick.

Surface Materials

The report area is covered primarily by a single basal till unit of regional extent. A few multiple till sections have been documented, but further work is needed to determine their exact nature and relevance (Seaman 2004).

The basal till unit comprises lodgement till, basal melt-out till, or deformation till (as classified by Brodzikowski and Van Loon (1987)), or any combination of these three members. Typically, a given locality features only a single member. However, some exposures display one member grading into another: basal melt-out till into lodgement till, for example, or lodgement till into deformation till. The basal till unit occurs mainly as a blanket or veneer covering large parts of the landscape, commonly reflecting the texture, lithology, and colour of local bedrock. Thickness of the unit generally ranges from 0.5 m to 1.5 m. In some areas, mainly on the lee side of topographic highs, the unit can reach thicknesses of about 5 m; elsewhere, it forms a veneer measuring only a few decimetres.

Rapid deglaciation is recorded by glaciofluvial deposits found mainly in overdeepened river valleys and glacial spillways, and by discontinuous disintegration moraine (ablation till deposits with associated ice-contact deposits) found in topographic depressions. Deglaciation in this region did not produce a recognizable sequence of end moraines. Rather, it appears to have caused ice-mass stagnation and in-place wastage (Seaman 2004). Figure 2 shows the distribution of eskers and major kame moraines in southwestern New Brunswick.

DATA SET PROPERTIES AND LEVELLING SCENARIOS

Till geochemical investigations in southwestern New Brunswick began in 1990 and are ongoing today (2005). The current report deals only with basal till geochemical data obtained between 1990 and 2003. The 2122 basal till samples were collected from the 21 G and 21 J map areas (Fig. 1) and represent a sample density of 1 sample/4 km².

Till geochemical data gathered over the 13-year period was obtained from several laboratories that used a variety of analytical techniques (Table 1). In the case of some elements, the resulting data set is characterized by systematic variations. The variations are systematic in that elemental values obtained from standard reference materials in one

survey tend to differ consistently from values obtained from the same standards in another survey: that is, the variations have similar parametric characteristics (Grunsky, in press).

To mitigate the effects of these inconsistencies and to produce a more accurate regional data set, levelling corrections can be applied. Levelling is the practice of applying a correction factor to the values of one survey to make them comparable to the values of another. Several scenarios in this data set warranted a levelling correction and are discussed in detail below. (Also see *Appendix 1*.)

Surveys conducted under the direction of Toon Pronk (NBDNR) employed Acme Analytical Laboratories Ltd., Vancouver, British Columbia, for ICP-MS analysis and Becquerel Laboratories Inc., Mississauga, Ontario, for INAA analysis. Surveys conducted by Allen Seaman (NBDNR) used Activation Laboratories Ltd. (Actlabs®), Ancaster, Ontario, for both INAA and ICP-OES analyses. In addition, surveys for the Fosterville, Forest City, and Canterbury map areas used AAS to determine base-metal concentrations. AAS was conducted by NBDNR staff prior to closure of the Department's AAS laboratory in 1993. Table 1 lists all publications related to the foregoing analyses.

The NBDNR conducted the first parametric levelling of its geochemical data in 2003 (Allard 2004). Prior to that time, the data were collected, analyzed, and published as reports and associated maps based on individual map-area projects. The approach successfully targeted new areas for exploration, and the resulting data proved useful to prospectors and junior mining companies operating in southwestern New Brunswick. However, comparisons made between non-levelled data sets potentially can result in misleading conclusions. Data levelling therefore is necessary when seeking to compare results from multiple surveys or to produce regional compilation maps and reports. Such compilation maps can be an excellent tool for assessing large-scale geochemical trends or delineating zones of high mineral exploration potential.

The current report presents levelled data for the following 26 elements: As, Au, Ba, Co, Cr, Cs, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Rb, Sb, Th, U, W, Zn, and the combined rare-earth elements (Ce, Eu, La, Lu, Sm, Tb, and Yb). Data for these elements were levelled to represent Actlabs® INAA values, except for Cu, Mn, Ni, Pb, and Zn, which were levelled to represent Actlabs® ICP-OES values. *Appendix 1* describes the levelling methodology used.

Levelling corrections were applied where significant variations in data were observed due to one or more of the following circumstances.

1. *Different analytical techniques.* Where different analytical techniques were used in the report area, levelling was conducted to create a new, coherent data set. In this report, data obtained from AAS by NBDNR staff was levelled to fit data obtained from ICP-OES by Actlabs®. Quantile analysis of standard data indicates that values

obtained from both methods have systematic parametric characteristics and therefore can be levelled. No AAS-ICP-OES levelling was required for Cu. On the other hand, ICP plots for Mn, Ni, Pb, and Zn all required some degree of AAS-ICP-OES levelling.

Data from ICP-MS by Acme, which used aqua regia (hydrochloric and nitric acids) partial extraction, were also levelled with data from ICP-OES by Actlabs®, which used near-total, four-acid (hydrochloric, nitric, perchloric, and hydrofluoric acids) digestion. The levelling procedure yielded regional data for Cu, Mn, Ni, Pb, and Zn. Again, quantile analysis of standard data indicated systematic parametric characteristics that permitted levelling of the data.

2. *Consistent analytical technique but different laboratories.* Two laboratories used INAA: Becquerel and Actlabs®. Standard data indicated that values obtained from each method were comparable for most elements. Minimal levelling was required, and only for the elements Cr, La, Lu, Rb, Sm, Ta, and Yb.
3. *Consistent analytical technique and laboratories but changes in detection parameters or digestion.* Laboratory techniques have altered considerably over the duration of this project. Since 1990, for instance, detection limits, accuracy, precision, and control over digestion conditions have been improved. Levelling corrections thus were applied as required to take into account the consequences of these technological and analytical advances.

In a few cases, different digestion methods were used, although the same laboratory and technique were employed. Specifically, two runs of ICP-OES (for the Fosterville and McAdam map areas) used aqua regia rather than four-acid digestion. Four-acid digestion is a substantially stronger dissolution than aqua regia digestion, but the results for some elements, including base metals, tend to be comparable (Hoffman 1999). Only Cu, Mn, Ni, Pb, and Zn are reported as ICP contour plots, and no notable discrepancy was observed at map boundaries, except in the case of the McAdam map sheet.

On the McAdam map sheet, Pb and Zn concentrations were considerably lower than on the surrounding map sheets. Noticeable edge effects were apparent in preliminary contour plots but could not be attributed solely to the variation in digestion techniques. Data for the Fosterville map sheet, for example, also were obtained using aqua regia digestion but did not show a similar discordant relationship. Therefore, the anomalously low Pb and Zn values (below background levels) for the McAdam map area must be due to variations in the detection parameters or digestion conditions for that specific run. This discrepancy was accounted for in the levelling process.

CONTOURING METHODS

The contour maps in this report show the geochemical relief (variations in concentration) across the surveyed area for individual elements (listed below) and for specific multivariate-element-association groupings (also listed below). The geochemical contours are displayed on page-sized maps (Fig. 7–11, 20–38) over a bedrock background that was derived from the 1: 500 000 *Bedrock Geology of New Brunswick* (NBDNRE 2000; also see Fig. 6 and Table 2). This visual presentation allows for enhanced recognition of anomalous zones, dispersal patterns, and bedrock-controlled geochemical trends. The maps can be used as a quick reference to distinguish areas with greater mineral exploration potential from those that are less favourable.

Map contours were generated by the Surfer® 8 software program using point kriging with a search radius of 8 km. Point kriging estimates values at grid nodes, employing a moving-average technique of contouring to compensate for the somewhat irregular spacing of sample sites. Statistically, kriging is based on *The Theory of Regionalized Variables*, wherein a variable is considered "regionalized" if it varies from one place to another with apparent continuity: in other words, trends are apparent in the data. Because such variation is evident in geochemical data, kriging is viewed as the method most suitable for geochemical contouring.

Surfer® 8 software allows the user to create an appropriate variogram model when gridding using the kriging algorithm. The variogram determines spatial continuity in the data set and measures how quickly values change with distance. It is a three-dimensional function that, when properly modelled and applied to the data, results in a more meaningful and natural representation of geochemical relief. By modelling the variogram through trial and error, and by employing Surfer's automated controls, the user allows the data to dictate the limits of reproducibility. All contour maps presented here have been subjected to variogram modelling (see *Appendix 2*).

The Multivariate Approach

The delineation of an anomaly with economic potential can often be enhanced by combining several geochemical parameters. In gold exploration, for instance, the values of not only gold, but also arsenic and antimony, among other pathfinder elements in till, should be considered. This is true, despite the fact that correlating the element values and defining element associations by examining data tables or single-element contour plots can be cumbersome and sometimes misleading, as exemplified by the so-called "nugget effect".

The odds of overlooking relevant anomalies can be significantly decreased by constructing multi-element pathfinder contour maps. The multivariate-element-association maps in this report (Fig. 7–11) are adapted from the element associations of Rose et al. (1979, p. 76:

Table 4.2). Equal weight is given to all constituents, whether they are major components or associated pathfinder components. The following steps demonstrate the data processing needed to determine an "indicator" value for contouring.

Step 1. The raw data are screened for "undetectables." These are replaced with a value equal to half the detection limit for that particular element.

Step 2. The raw data are normalized by dividing the value of each element by its mean so that all elements are given equal weight in the resulting "indicator" value.

Step 3. The normalized values are summed (e.g. $W + Mo + Cu + Rb + Cs = \text{tin-tungsten indicator}$).

Step 4. The new "indicator" value is converted to its corresponding percentile value. This is the value that is contoured.

MULTIVARIATE-ELEMENT-ASSOCIATION CONTOUR MAPS

Five multivariate-element-association contour maps have been constructed to aid in identifying favourable areas for the types of mineralization expected to occur in southwestern New Brunswick. The maps show indicator contour plots for precious-metal mineralization (Fig. 7), base-metal mineralization (Fig. 8), tin-tungsten mineralization (Fig. 9), nickel-cobalt-copper mineralization (Fig. 10), and rare-metal mineralization (Fig. 11). Significant metal anomalies are marked on the contour maps by upper-case letters (e.g. A, B, C) and are discussed below.

Concentration contour maps (Fig. 20-37) also have been plotted for 18 individual elements (As, Ba, Co, Cr, Cs, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Rb, Sb, Th, U, W, and Zn). These maps appear in *Appendix 3*, together with an indicator contour map for combined rare-earth-element concentrations (Fig. 38).

Although data levelling has produced an accurate representation of the till geochemical data, corrections cannot be made for specific naturally occurring phenomena. Caution thus should be exercised when comparing magnitudes of anomalies situated distal to one another in the report area. Variations in bedrock lithology and geochemistry (regional geochemical relief), differences in localized glacial dynamics, and till genesis all can affect the anomaly contrast with respect to source. Till in the report area presumably is locally derived, but differences in geochemical relief can (and likely do) result from varying degrees of till homogenization and reworking. For example, basal till overlying the Pokiok Batholith in the Forest City (21 G/12) map area has a locally derived sandy, granitic matrix, but a pebble fraction dominated by distally derived sedimentary and volcanic clasts (Seaman 1992).

Care also must be taken when comparing anomalies hosted in the different geological zones (Fig. 5). Allard (2003) has characterized background, threshold, and anomalous geochemical values using quantile analysis of 49 elements in the Fredericton Zone and St. Croix Zone for 272 till samples from the Rollingdam (21 G/06) map area. The Rollingdam data indicate that, for most elements, these parameters are noticeably lower in the Fredericton Zone than in the St. Croix Zone. In other words, transitions from one uniform geochemical "province" to another tend to be sharp and consistent with zone boundaries. Abrupt transitions attest to the dominantly local nature of the till and the efficiency of material incorporation and deposition by the ice mass.

Notwithstanding the foregoing limitations, the contour maps accompanying this report show anomalies that 1) have consistently high above-background concentrations, 2) display apparently high potential, and 3) can be readily discerned, regardless of setting.

Precious-Metal Mineralization

The precious-metal-mineralization indicator map (Fig. 7) represents a composite of normalized Au, Sb, As, Hg, Th, and U concentrations in basal till. The report area hosts numerous precious-metal anomalies. Some occur at sites of proven economic potential such as Clarence Stream (A on Fig. 7), Sorrel Ridge (B), Poplar Mountain (C; Seaman 1994), and Lake George (E). Other anomalies show surface expressions similar in magnitude to those at A, B, C, and E and occur in settings tectonically favourable for hosting potentially economic-grade deposits. However, these anomalies, which include ones at Sisson Brook (D) and Tower Hill (F; Allard, in press), have not undergone substantial follow-up work. Ruitenberg et al. (1990) present a summary guide to geological controls on precious-metal mineralization in the report area.

Smaller precious-metal anomalies on Figure 7 generally appear as "bull's-eye" and "amoeboid" shapes (Shilts 1975) or as small palimpsest configurations (Parent et al. 1996), all of which depict identifiable point sources. The larger, compound anomalies (e.g. A, B, and D) exhibit irregularly homogenized configurations that reflect the hybrid nature of the till. (Hybrid till was reworked by glacial flow paths, which "hybridized" the original till, redistributing its matrix and clast components. See *Considerations Relating to Glacial History*, below, for more detail.) These larger anomalies likely indicate proximal, multiple-point sources and areas of substantially higher background geochemical concentration related to underlying bedrock units.

Based on the precious-metal contour map (Fig. 7), several generalizations can be made concerning follow-up exploration targets. Many anomalies appear in close proximity to documented mineral occurrences, but other anomalies do not. Moreover, some anomalies coincide with mineral occurrences for commodities other than precious metals. For example,

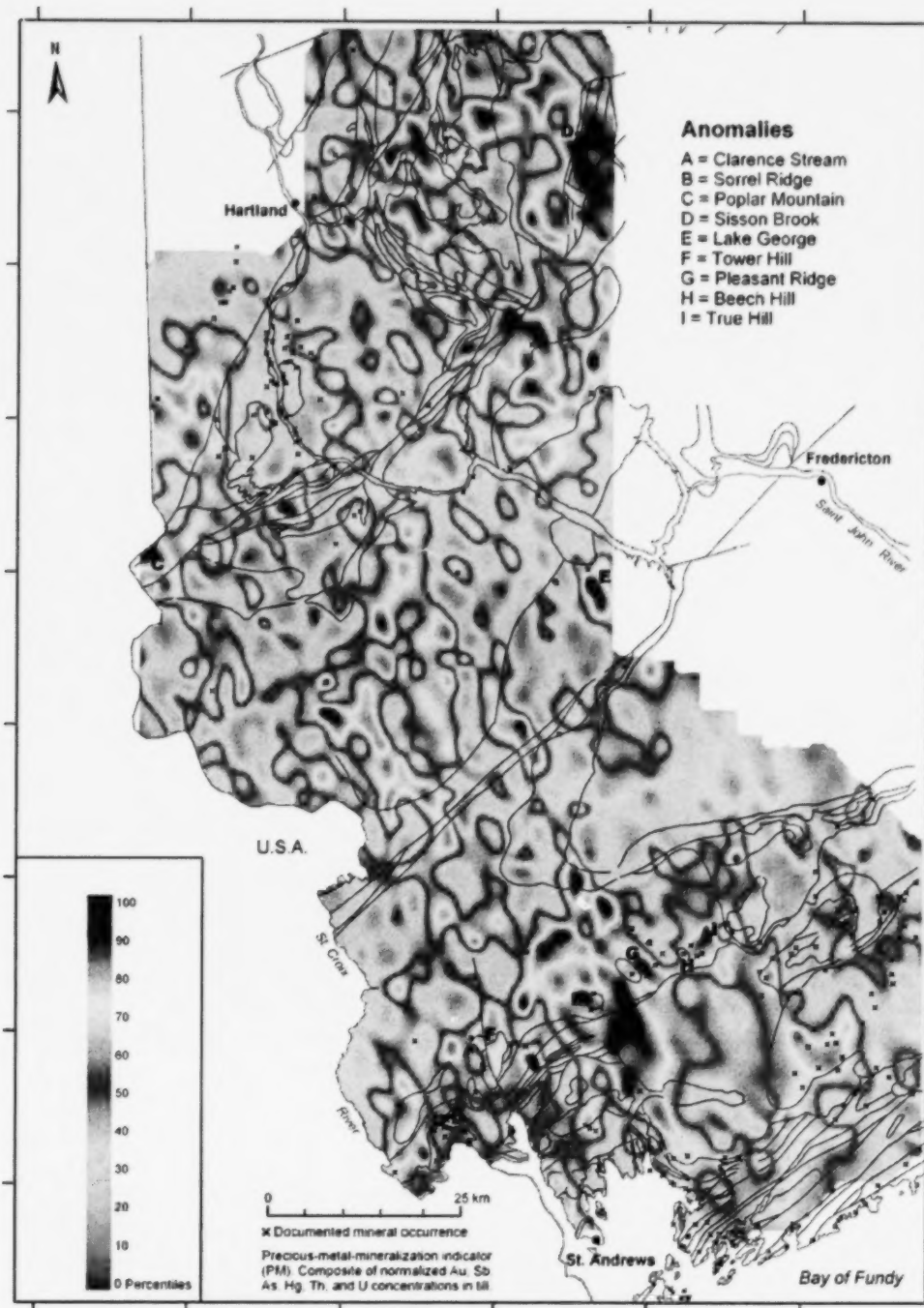


Figure 7. Multivariate precious-metal-mineralization indicator in basal till (< 63 μ m fraction).

a significant precious-metal anomaly near Pleasant Ridge (G) overlays the eastern flank of the Late Devonian Pleasant Ridge pluton at its contact with sedimentary country rock. Documented mineral occurrences related to the intrusions describe base-metal and tin mineralization. This situation also pertains to anomalies associated with the Late Devonian Beech Hill (H) and True Hill (I) plutons.

Another factor to consider when examining anomalies near documented mineral occurrences is how the glacial dispersal direction relates to the position of the anomaly "head" (that is, the peak concentration contour) and mineral occurrence location. The Tower Hill (F) anomaly, for instance, occurs along the northwestern margin of the Tower Hill pluton, but the only known precious-metal occurrences lie east of the pluton. Glacial dispersal in the area is primarily toward the southeast. Because the surface anomaly expression is almost instantaneous in this region (as indicated by thin tills), it is unlikely (although not impossible) that an anomaly head oriented any distance north of a documented mineral occurrence could be related to that occurrence.

Overall, the precious-metal-mineralization indicator map shows a high potential for precious metals in southwestern New Brunswick. Many of the anomalies (Fig. 7) overlay areas that have undergone little mineral exploration and thus warrant follow-up work.

Base-Metal Mineralization

The base-metal-mineralization indicator map (Fig. 8) represents a composite of normalized Cu, Pb, Zn, Mn, As, Sb, and Au concentrations in basal till. As with the precious-metal contour map, the base-metal contour map shows numerous high-contrast anomalies. However, distribution of these anomalies is less sporadic than for precious metals and is more confined to specific geological zones.

Most base-metal anomalies occur in the northern part of the report area within the Miramichi Zone and the southern extension of the Tobique–Chaleur Zone (Fig. 5). The peak anomaly (99th percentile) overlays rocks of the Tobique–Chaleur Zone in an area targeted by Ruitenberg and McCutcheon (1982) as having high potential for stratabound massive-sulphide deposits. Anomaly A (Fig. 8) overlays Early Carboniferous sedimentary rocks of the Mabou Group. The anomaly "head" coincides with a contact between Early Devonian mafic volcanic rocks of the Tobique Group and Carboniferous rocks. A compound anomaly of almost equal magnitude (98th percentile) occurs in the vicinity of Sisson Brook (B on Fig. 8). Anomaly B straddles multiple bedrock units including the Early Devonian Howard Peak pluton, Ordovician volcanic rocks of the Meductic Group, and Late Cambrian–Early Ordovician sedimentary rocks of the Woodstock Group. The position of the anomaly "heads" relative to nearby documented mineral occurrences suggests that additional sources of mineralization may exist nearby. Many other anomalies identified in the northern part of the report area also deserve further investigation (Fig. 8).

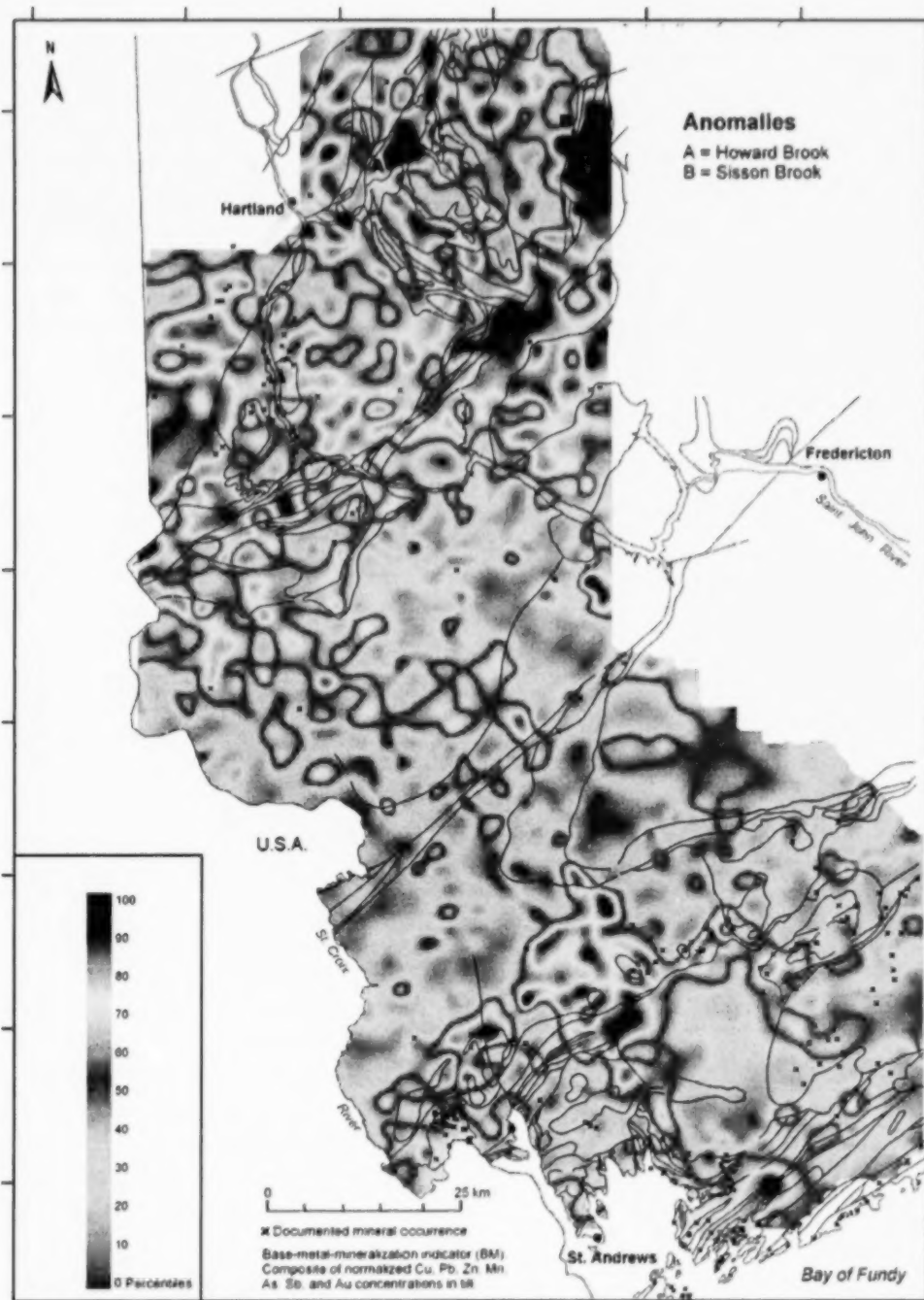


Figure 8. Multivariate base-metal-mineralization indicator in basal till (< 63 μ m fraction).

Most base-metal anomalies in the southern part of the report area occur proximal to the boundary between the St. Croix Zone and the Mascarene Zone (Fig. 5). Although the area is not known for high base-metal potential, the anomalies here justify follow-up activity (Fig. 8).

Tin-Tungsten Mineralization

The tin-tungsten-mineralization indicator map (Fig. 9) represents a composite of normalized W, Mo, Cu, Rb, and Cs concentrations in basal till. Map anomalies are confined primarily to the Miramichi Zone and St. Croix Zone, situated in the northern and southern parts of the report area respectively (Fig. 5). Ruitenberg and McCutcheon (1982) describe tungsten-molybdenum mineralization in the region as being stockwork in greisen.

Peak tin-tungsten anomalies in the northern portion occur in the Coldstream (NTS 21 J/06) map area near Sisson Brook (A on Fig. 9) and in association with Early Carboniferous rocks of the Mabou Group (B). The compound anomaly at Sisson Brook forms a disjointed band of highly anomalous ($> 98^{\text{th}}$ percentile) values spanning several bedrock units. Related mineral occurrences have been documented but, again, configuration of this anomalous zone indicates high potential for additional sources of mineralization. Snow and Coker (1987) describe overburden geochemistry at Sisson Brook and relate it to known W-Cu-Mo mineralization in the area.

The source of anomaly B (Fig. 9) overlying Early Carboniferous sedimentary rocks of the Mabou Group is unknown; this attractive area deserves further investigation. Interestingly, a sizeable dispersal train emanates from the rock suite and extends southeast for approximately 20 km (Seaman 2001b). This indicates a significant displacement of material, assuming that no additional sources of mineralization are situated along the trajectory.

Although geochemical relief in the south part of the report area is less than in the north, the St. Croix Zone in New Brunswick (Fig. 5) historically has been a target area for tin-tungsten exploration. The region features numerous mineral occurrences containing tin-tungsten and related commodities, and many anomalies are associated with these occurrences (Fig. 9). One such deposit is the past-producing Mount Pleasant mine (Sn, W, In, and Bi) although, curiously, the mine site (C on Fig. 9) shows a lower than expected geochemical relief. Szabo et al. (1975) discuss Cu, Pb, Zn, As, and Sn in the Mount Pleasant area, as well as glacial dispersal of till pebbles.

Ruitenberg and McCutcheon (1982) describe host rocks for tin-tungsten mineralization in the report area as being Late Devonian high-silica granite stocks and associated contact aureoles. Some anomalies on the tin-tungsten contour map (Fig. 9) show definite associations with such intrusions including those in the areas of McDougall Brook (near C), Sorrel Ridge (near D), and Pleasant Ridge (near E). Conversely, other anomalies on Figure 9 show relief equal to that of anomalies C to E but appear not to be associated with granitic intrusions or aureoles.

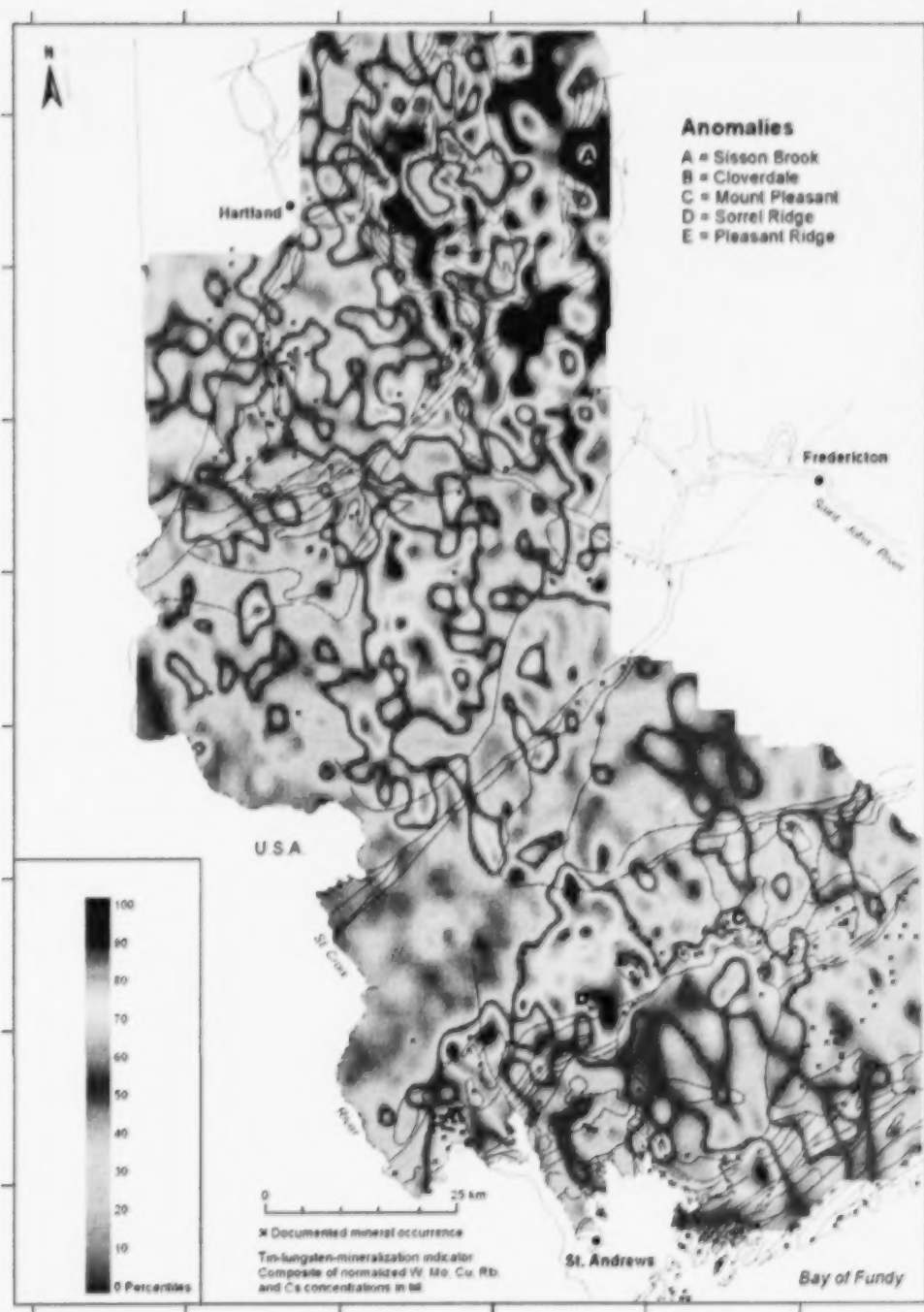


Figure 9. Multivariate tin-tungsten-mineralization indicator in basal till (< 63 μ m fraction).

Nickel–Cobalt–Copper Mineralization

The nickel–cobalt–copper-mineralization indicator contour map represents a composite of normalized Ni, Co, Cu, and Cr concentrations in basal till (Fig. 10). High-contrast anomalies of this mineralization type are limited to the St. Croix Zone and Miramichi Zone located in the southern and northern parts of the report area respectively (Fig. 5).

Numerous mineral occurrences have been documented in ultramafic and mafic phases of the Late Silurian St. Stephen intrusion around St. Stephen (Fig. 10). Their associated anomalies expressed in the overlying basal till consistently show > 90th percentile values. Anomalies in the St. Croix Zone include those at St. Stephen (A of Fig. 10) and two bull's-eye anomalies underlain by the Silurian Allen Brook (B) and Foster Lake (C) mafic intrusions. Another noteworthy anomaly occurs at Utopia (D) in association with mafic rocks of the Early Silurian Mascarene Group. Significantly, all five multivariate-element-association maps consistently show an anomaly at this location.

Delineating anomalous patterns of nickel–cobalt–copper mineralization in the northern portion of the report area is less straightforward than in the south. Although many anomalies overlay mafic volcanic rocks and mafic intrusions, another large group of anomalous values (E on Fig. 10) are associated with manganese-rich sedimentary rocks of the Silurian Perham Group. Considerable glacial dispersal to the east and south–southeast from this area has produced a zone of above-background concentrations. No occurrences of mineral commodities related to this mineralization type have been documented here. However, grab samples from bedrock in the area were analyzed using INAA and ICP-OES (four-acid dissolution) and showed above-background Ni and Co concentrations (Seaman 2000). Whether these elevated values in bedrock and the overlying till reflect a potential source of economic mineralization is unclear; the district warrants further investigation.

No relevant mineral occurrences have been documented at any of the nickel–cobalt–copper anomalies associated with mafic rock units in the northern part of the report area. Anomalies F, G, H, and I (Fig. 10) appear related to mafic rocks of the Early Devonian Tobique Group. The sizeable, high-contrast, bull's-eye anomalies J and K (Fig. 10) overlay the Early Devonian Becaguimec Lake mafic intrusion.

Rare-Metal Mineralization

Normalized Cs, Rb, U, Th, Ce, Eu, La, Sm, Tb, and Yb concentrations in basal till were used to compile the rare-metal-mineralization indicator map (Fig. 11). Peak concentrations are found in the northern part of the report area. Here, a broad zone of anomalous concentrations (A on Fig. 11) occurs in close association with Early Devonian intrusions (> 99th percentile head) including the Nashwaak and Howard Peak plutons, and the northern extension of the Hawkshaw pluton.

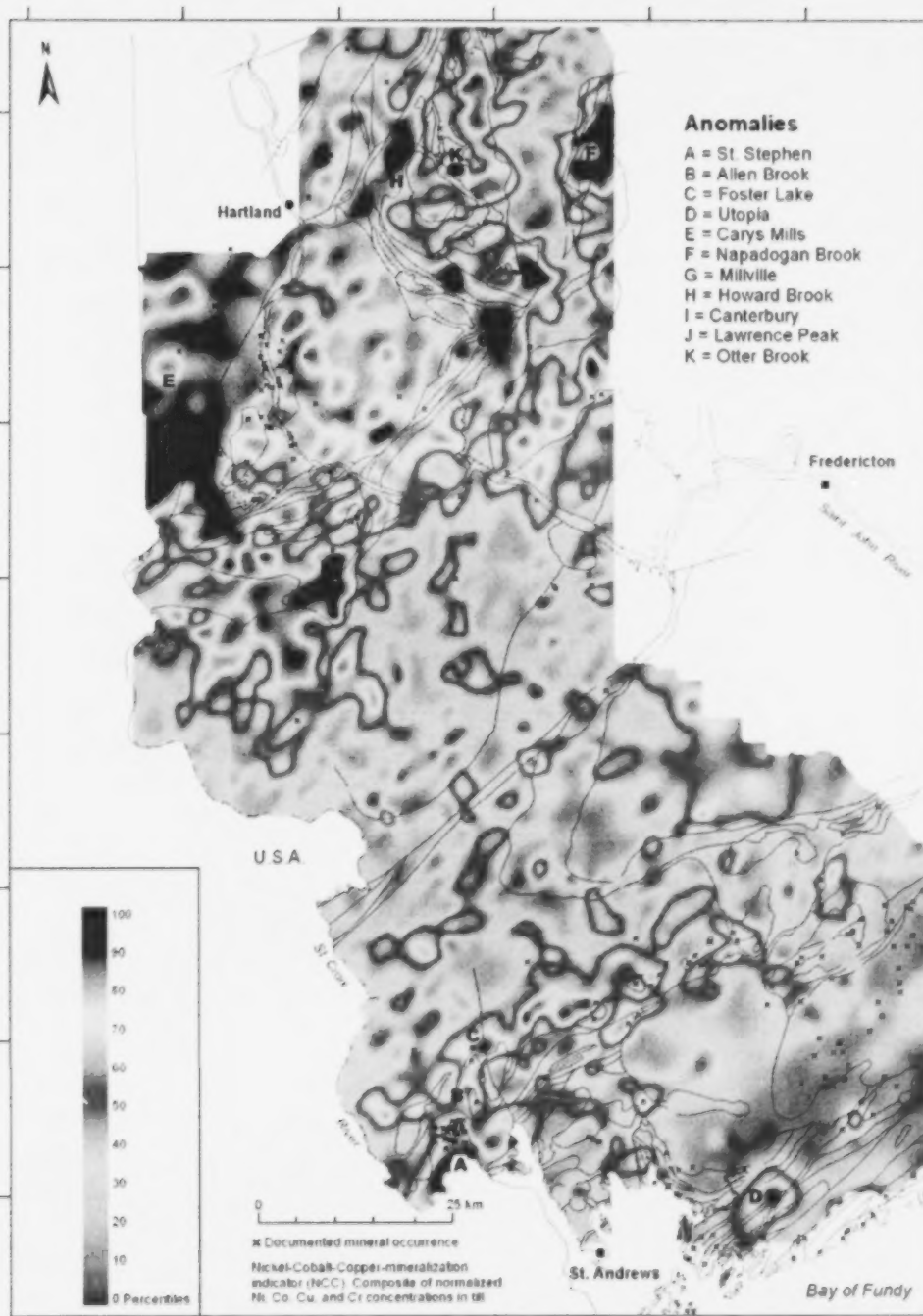


Figure 10. Multivariate nickel-cobalt-copper mineralization indicator in basal till (< 63 μ m fraction).

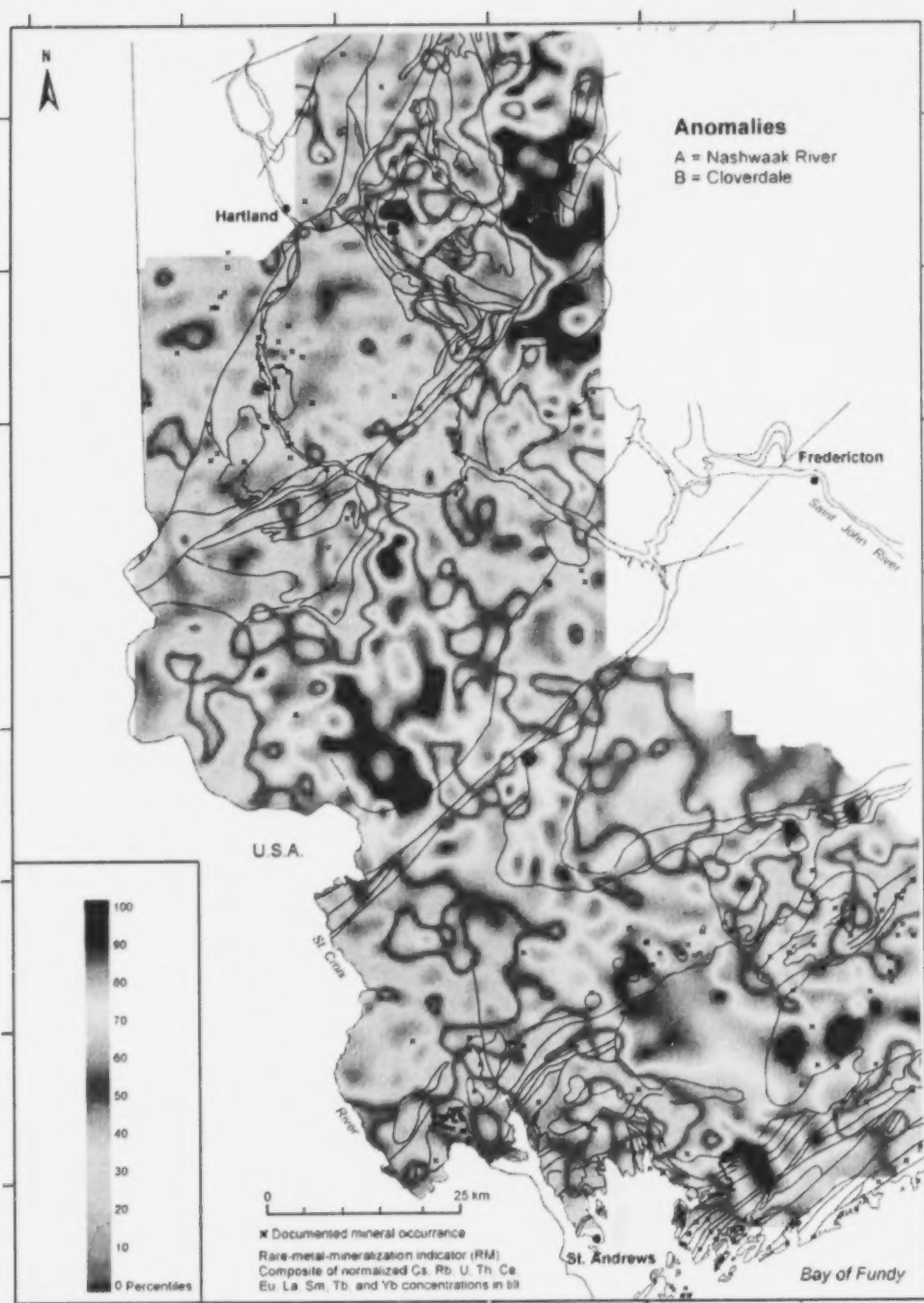


Figure 11. Multivariate rare-metal-mineralization indicator in basal till (< 63 μ m fraction).

West of these sites, and of particular interest, is a high-contrast (> 99th percentile), well defined, amoeboid-shaped anomaly (B on Fig. 11) that indicates a point source. Anomaly B overlays Early Carboniferous sedimentary rocks of the Mabou Group, even though anomalies of such extreme relief generally are not expected to occur diagenetically in sedimentary rocks. The anomaly may represent placer deposition of heavy minerals and deserves further investigation.

In the middle and southern parts of the report area, broad, diffuse zones of rare-metal anomalies occur in association with several Devonian and, to a lesser extent, Late Neoproterozoic felsic intrusions (Fig. 11).

CONSIDERATIONS RELATING TO GLACIAL HISTORY

The complex Wisconsinan history of New Brunswick and the resulting glacial landscape present unique challenges to interpreting the timing and orientation of glacial events (Parkhill and Doiron 2003). As such, they pose several problems related to drift exploration. The complex erosional record (Fig. 12) is difficult to interpret (Seaman 1989a; Seaman et al. 1993), till fabric studies are inconclusive (Seaman 1991; Seaman et al. 1993), and datable Quaternary organic material is rare. Compounding these issues is the fact that provenance studies via geochemical dispersal must take into account 1) the extensive Late Wisconsinan hybridization of the till, and 2) the diverse bedrock geology of the province and its associated varying background geochemistry.

The report area is dominated by a single stratigraphic basal till unit consisting of basal melt-out till, lodgement till and, in some districts, deformation till. The basal till unit likely was deposited during the Early–Middle Wisconsinan Caledonia Phase of glaciation (Table 3). The Caledonia Phase appears to have comprised an Early Wisconsinan east–southeast erosional phase followed by a Middle Wisconsinan south–southeasterly depositional flow event (Rampton et al. 1984; Stea et al. 1998; Seaman 2004).

After till deposition, the single till unit underwent extensive reworking and hybridization during a series of Late Wisconsinan ice-flow phases (Stea and Finck 2001; Allard 2003; Allard and Pronk 2003; Seaman 2003b). These phases (Table 3) represent shifts in outflow orientation within a common ice sheet, rather than multiple advances and retreats by individual ice masses (Seaman et al. 1993). In the Rollingdam map area, for instance, Allard (2003) interpreted some till dispersal patterns and palimpsest landforms as being related to a Late Wisconsinan ice-flow event that followed a south–southwest (200° to 220°: Chignecto Phase) flow trajectory (Fig. 13, Table 3). A few-degrees shift in outflow direction and a subsequent creep of ice mass along the new trajectory for only tens of metres apparently were sufficient to produce a new set of striae.

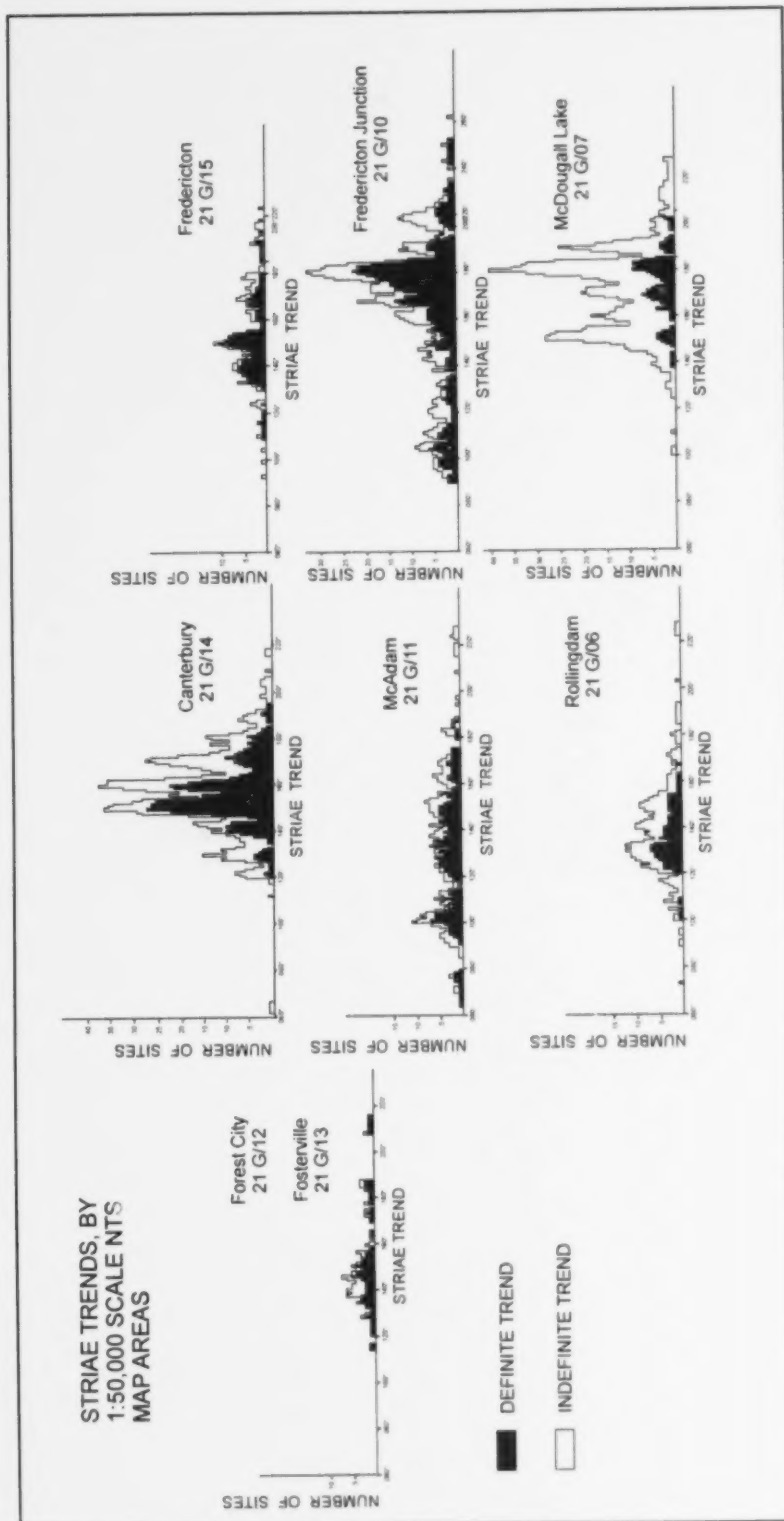


Figure 12. Histograms for observed striae trends in southwestern New Brunswick.

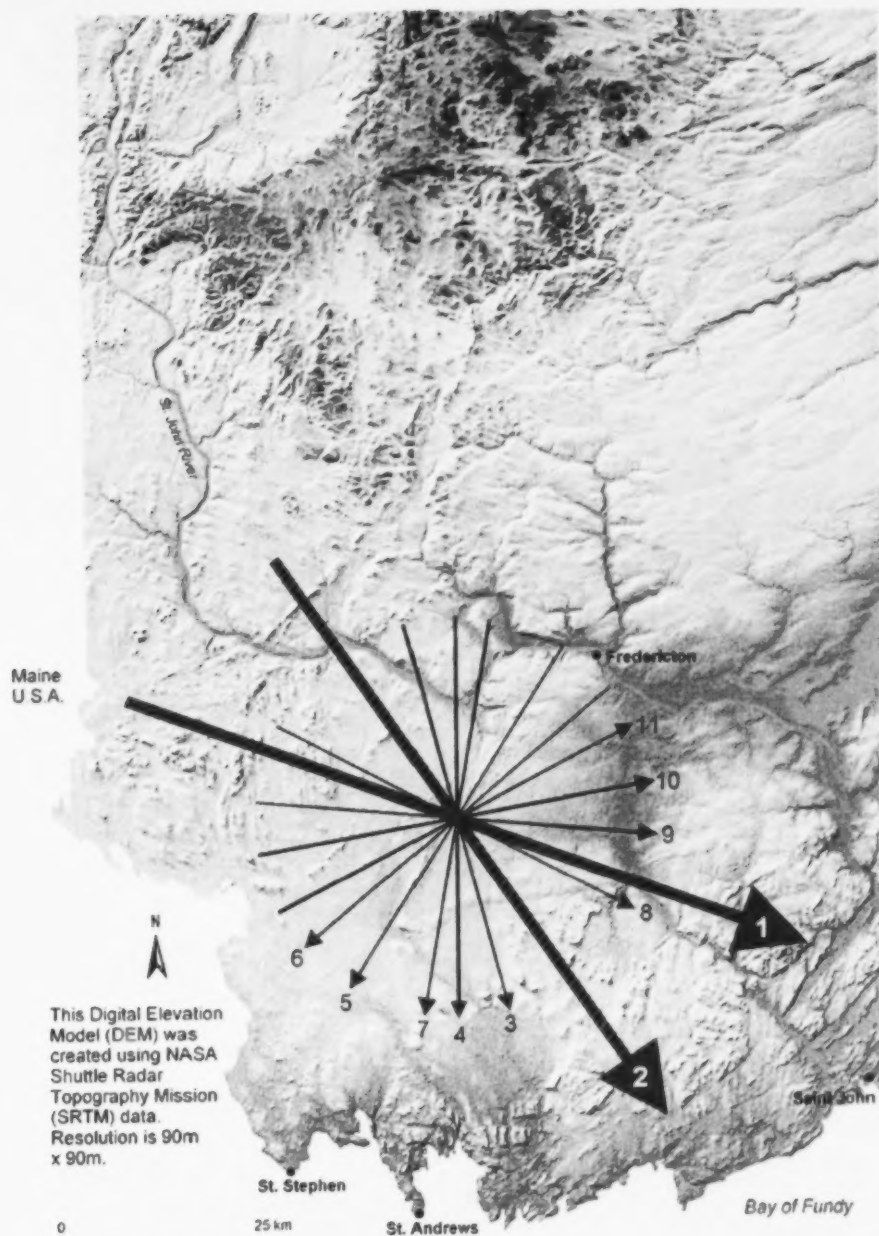


Figure 13. Ice-flow trajectories (No. 1 to 11) across southwestern New Brunswick. Diagram does not show the source area or terminal position. Table 3 lists glacial phase names and orientations associated with each numbered trajectory.

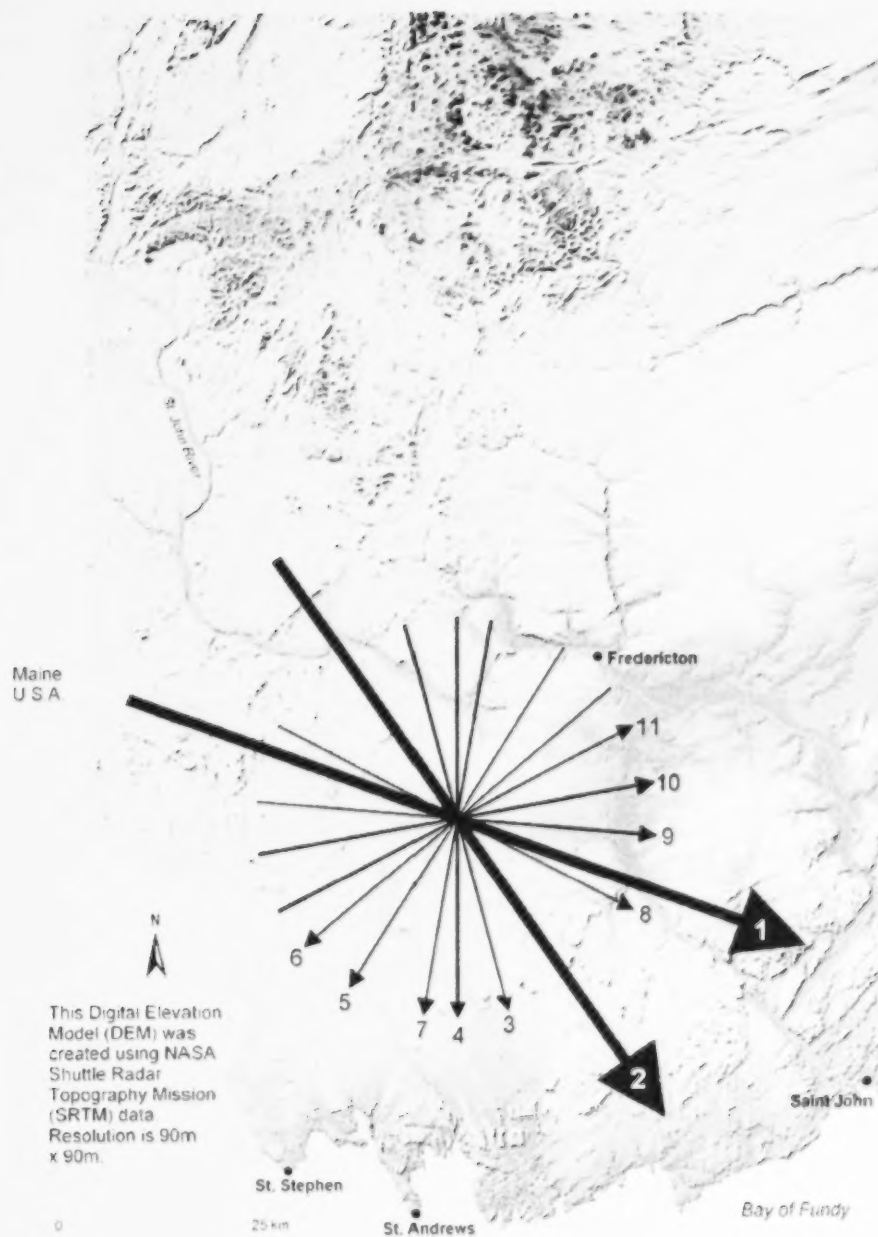


Figure 13. Ice-flow trajectories (No. 1 to 11) across southwestern New Brunswick. Diagram does not show the source area or terminal position. Table 3 lists glacial phase names and orientations associated with each numbered trajectory.

Table 3. Ice-flow chronology for southwestern New Brunswick.

Reference No. on Figure 13	Phase	Flow Trajectory	Inferred Age
11	Pollet River	55°–70°	Late Wisconsinan
10	Kent	70°–90°	Late Wisconsinan
9	Tuadook–Renous	90°–100°	Late Wisconsinan
8	Passamaquoddy	100°–135°	Late Wisconsinan
7	St. Martins	185°–195°	Late Wisconsinan
6	Port Elgin	220°–240°	Late Wisconsinan
5	Chignecto	205°–220°	Late Wisconsinan
4	Tantramar–Norton–Oromocto	175°–185°	Late Wisconsinan
3	Woodstock	155°–175°	Late Wisconsinan
2	Late Caledonia	135°–155°	Middle Wisconsinan
1	Early Caledonia	110°–120°	Early Wisconsinan

These variations in outflow orientation did not produce a recognizable till deposit. Instead, they altered the physical properties of the pre-existing till through increased homogenization, redistribution of the matrix and clast components, and re-alignment of the clast fabric. The result is a hybrid till with characteristics inherited from the multiple phases within one glacial episode (Allard and Pronk 2003; Seaman 2003b). The complex erosional landforms and striae patterns in southwestern New Brunswick record these Late Wisconsinan dynamics (Seaman 2004). Table 3 and Figure 13 summarize the current interpretation of ice-flow chronology in the region, based on striae crosscutting relationships and limited stratigraphy (Seaman 2004).

Despite the complex Late Wisconsinan glacial history, Early and Middle Wisconsinan trends remain discernable, albeit somewhat diffuse and homogenized. The predominant dispersal direction in southwestern New Brunswick (Fig. 13) is 135° to 155° (Late Caledonia Phase) and, to a lesser extent, 110° to 120° (Early Caledonia Phase). Transport distances are highly varied. Till clast provenance studies (such as Allard 2003) indicate that much of the till at a given location is of relatively local origin. In the report area, maximum transport distances for the clast component are approximately 20 km to 30 km (Allard 2003). The matrix component of the till would be expected to represent more distal sources but, as demonstrated on the contour maps (Fig. 7–11, 20–39), anomaly expression in the < 63 µm fraction of the till is almost instantaneous, as the anomaly head consistently occurs close to the presumed source. In the matrix component, geochemical dispersal trains tend to be diffused within 10 km of the presumed source. Many anomalies define bull's-eye patterns or slightly elongated amoeboid shapes with an exponential decrease in concentration down ice.

CONCLUSIONS

Till geochemical data from southwestern New Brunswick have been successfully combined and levelled using values from multiple surveys that employed several analytical techniques and different laboratories. This first attempt to level geochemical data represents a pilot project for the NBDNR. Future levelling methods are expected to improve through the possible use of a weighted regression quantile levelling technique similar to that used by Daneshfar and Cameron (1998). Their method allows more flexibility in weighting specific (heavily populated) quantiles than does the equal-weight linear regression technique.

The multivariate-element-association maps (Fig. 7-11, 38) represent a valuable aid in defining high-potential areas for particular types of mineral deposits. The maps reveal numerous till geochemical anomalies that warrant further investigation and, as such, will likely stimulate additional exploration activity in southwestern New Brunswick.

Production of mineralization indicator contour maps is a NBDNR priority, and future refinements are expected to improve usefulness of the maps. Meanwhile, the following recommendations have emerged as a result of this pilot project.

1. To minimize the need for levelling in the future, the number of analytical methods (including digestion conditions where applicable) and laboratories used should be kept to a minimum. Increasing diversity in the data set causes greater complexity of the levelling process and, in turn, lessens reliability of the levelled data.
2. Before beginning a regional or provincial levelling project, it may be beneficial to extract approximately 10 samples from each 1:50 000-scale survey for re-analysis in a single batch (one run) using the technique to which the data will be levelled (such as INAA, ICP-MS, and ICP-OES). The procedure would provide a solid baseline for parametric levelling of the data.
3. Parametric levelling should be the method of choice in adjusting values from adjacent surveys. Unlike quantile regression techniques, which require data selection on the basis of geographic location or bedrock characteristics, parametric levelling is based solely on the comparison of reference data in the form of duplicates or standards. Parametric levelling should yield excellent results as long as sufficient duplicate data are available over a wide range of concentrations (low register to high register).
4. To improve the status of ICP-OES-ICP-MS levelling in southwestern New Brunswick, an extraction of ICP-MS survey samples (~10-20) representing a wide range of concentrations should be re-analyzed using ICP-OES and vice versa. This would improve the reference set used in the levelling processes.

5. For the sake of consistency, an extraction of samples from southwestern New Brunswick surveys that used ICP-OES (aqua regia digestion) — that is, the McAdam and Fosterville surveys — should be re-analyzed using ICP-OES (four-acid digestion). This would improve the baseline for levelling and would offer additional insight into why base-metal concentrations for the McAdam survey are anomalously low.

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APPENDIX 1. LEVELLING TECHNIQUES

Correction factors for varied data were computed using two techniques: parametric levelling and quantile regression levelling (Darnley et al. 1995). A combination of both techniques was required for some elements, depending on the availability of standard reference values.

Parametric Levelling

Parametric levelling can be applied where several samples from the survey have been re-analyzed using the technique employed in the reference survey, or where standard reference data exist for both surveys. These control data from same-site samples, or standards, are displayed as x-y plots with similar x- and y-axis scaling. For convenience, the reference survey data are plotted against the x-axis, whereas the data to be levelled is plotted against the y-axis (Fig. 14).

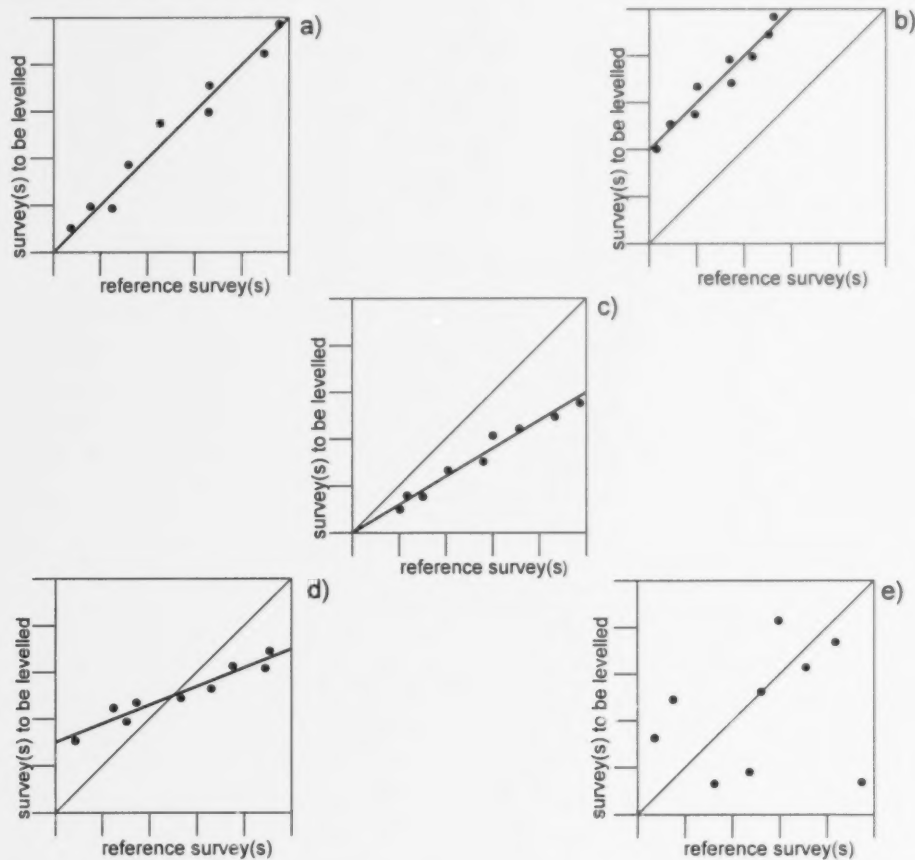


Figure 14. Potential scenarios that require parametric levelling. a) No levelling required. b) Shift required. c) Multiplier required. d) Both shift and multiplier required. e) Levelling not possible. Diagram modified after Darnley et al. (1995).

If the resulting data plot as a 45° diagonal, levelling is not required (Fig. 14a). If the data plot away from the diagonal but show a linear relationship to it, a correction factor can be applied and the data levelled. For example, if the data exhibit a variation in the y-axis intercept (parallel to the diagonal, either above or below), a shift correction can be applied through simple addition or subtraction (Fig. 14b). If the slope of the data varies from the diagonal, a multiplier correction equal to the variation in slope is applied to level the data (Fig. 14c). If both the intercept and slope differ, then both shift and multiplier corrections must be applied (Fig. 14d). Levelling is not possible when the data plot randomly about the diagonal with no discernable slope (Fig. 14e).

Drawing a line of linear regression through the data helps to better assess the spatial relationship. Where a large amount of control data exists (as in the Fosterville survey, which required 28 re-analyses for ICP-OES-AAS levelling), 10 quantiles are calculated and plotted rather than the data as a whole.

Quantile Regression Levelling

Quantile regression levelling is conducted where control data are not available to facilitate parametric levelling (Conradsen et al. 1991). This regression process uses multiple control points (10 quantile values), unlike crude past procedures where one data set was levelled to another simply by compensating for their discrepancy in mean value.

To successfully apply the quantile method, it is of utmost importance that the survey areas have similar environmental characteristics. Darnley et al. (1995) state that, for the procedure to be valid, data must be available from a common geochemical landscape in two or more surveys with similar bedrock that has undergone similar erosional and secondary environmental histories. In the present report, care was taken to level only those surveys with similar bedrock characteristics and geochemical relief. Surveys from adjacent areas were found to best meet these criteria.

It is important to apply quantile regression levelling only where warranted: the objective of geochemical compilations is to identify anomalies at the regional scale, not to mask them by minimizing their surface expression. The quantile regression levelling is partly a subjective process. Because no exact solution exists to a given levelling problem, various compilers may reach slightly different conclusions using the same data.

In the quantile regression process, multiple surveys are selected as the "reference" to which other surveys are levelled. Ten quantile values, corresponding to the 10th, 20th, 30th ..., 80th, 90th, and 95th percentiles are calculated from the combined data of the "reference" survey and the survey data to be levelled. These values are displayed on an x-y plot with similar x- and y-axis scaling, and the data sets are levelled using the same procedure as was described for parametric levelling.

The Levelling Process in Action, Using Zinc Data

The zinc data set for southwestern New Brunswick is the combination of 1) ICP-OES values from 21 G/11, G/13, G/14, 21 J/03, J/04, J/06, 2) a small amount of AAS data from 21 G/12, G/13, G/14, and 3) ICP-MS data from 21 G/02, G/03, G/06, G/07, and G/10 (Table 1). Unlike most elements, which require only minimal adjustment, the zinc data set requires three degrees of levelling and incorporates most of the levelling situations described above. The zinc data set thus can be used to best illustrate the step-by-step levelling procedure.

Step 1

The first step involves levelling AAS data with ICP-OES data. The parametric technique is applied because an adequate amount of control data exists in the form of multiple re-analyses of standard reference material by both analytical procedures. Data from these standards are not directly used in the levelling process; instead, quantiles corresponding to the 10th, 20th, 30th ..., 90th, 95th percentiles are used (Table 4). A discrepancy, albeit a minor one, is evident between the corresponding ICP-OES and AAS percentile values (Fig. 15). In this case, a simple multiplier correction factor is adequate to level the data (Table 4).

$$\text{Zn ppm: ICP-OES values} = \text{AAS values} \times 1.1$$

Step 2

The second step involves levelling ICP-MS data from map sheets 21 G/02, G/03, G/06, G/07, and G/10 with the ICP-OES data from 21 G/11, G/13, G/14, 21 J/3, J/04, and J/06. In this case, parametric levelling is applied using reference standards as control data. These reference standards consist of the Geological Survey of Canada standards TILL-1, -2, -3, -4, and STSD-4 (Lynch 1990, 1996) and the New Brunswick Department of Natural Resources standards NB-01, NB-02, and NB-CS1 (Table 5). Because these standards have undergone multiple runs of analyses using both analytical techniques in question, their respective average values can be used in the levelling process (Table 5).

ICP-MS values tend to be somewhat lower than ICP-OES values, except in the high register of analysis (Table 5). Because they demonstrate a linear relationship (Fig. 16), levelling of the two data sets is possible. Here, a shift correction, as well as a slight multiplier correction, is required to level the data.

$$\text{Zn ppm: Actlabs® ICP-OES values} = (\text{ACME ICP-MS values} + 8) \times 1.06$$

Step 3

The final step of the zinc levelling process involves levelling the McAdam (21 G/11) survey to that of the surrounding map areas. Preliminary regional Zn contour plots (completed after the ICP-OES-ICP-MS levelling) show considerable edge effects associated with the McAdam

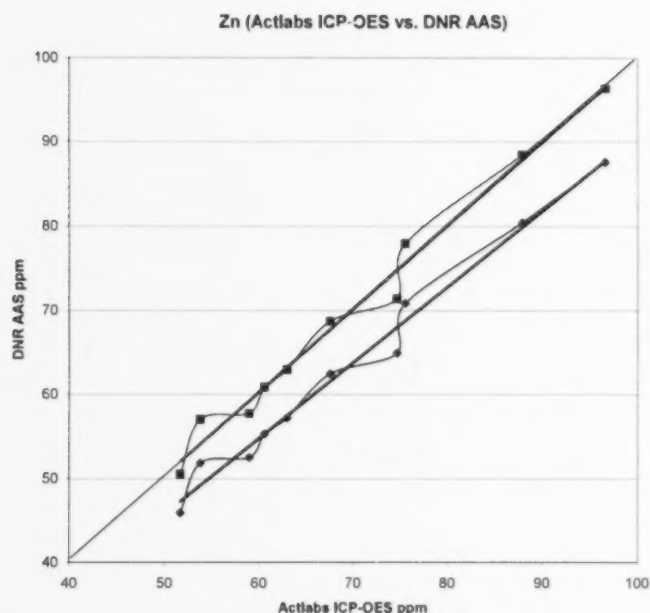


Figure 15. Zn x-y plot used to aid in levelling AAS data with ICP-OES data from the Forest City (21 G/12) and Fosterville (21 G/13) surveys. The curved blue line represents the contrast in the ICP-OES and unlevelled AAS data, whereas the curved red line represents a comparison between the ICP-OES data and levelled AAS data. The solid blue and red lines are linear regression trend lines. Each data point (shown as a blue or red square) corresponds to a percentile value. From left to right, they are the 10th, 20th, 30th ..., 90th, and 95th percentiles, as listed on Table 4, below.

Table 4. Levelling Step 1: Levelling AAS Zn data with ICP-OES Zn data.

	Zn (ppm) Actlabs® ICP-OES Fosterville samples	Zn (ppm) DNR AAS Fosterville samples	Correction Factor: ICP-OES = AAS x 1.1
No.	28	28	
Minimum	43	40	
Maximum	108	138.9	
Mean	67	62.6	
10th %ile	51.70	45.93	50.52
20th	53.80	51.82	57.00
30th	59.00	52.50	57.75
40th	60.60	55.30	60.83
50th	63.00	57.20	62.92
60th	67.60	62.44	68.68
70th	74.70	64.90	71.39
80th	75.60	70.86	77.95
90th	87.95	80.41	88.45
95th	96.65	87.59	96.35

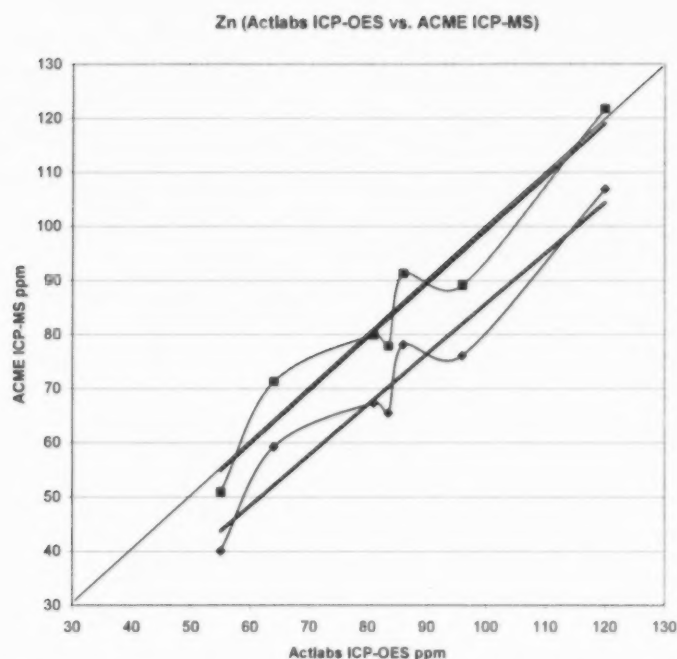


Figure 16. Zn x-y plot used to aid in levelling ICP-MS data with ICP-OES data. The curved blue line represents the contrast in the ICP-OES and unlevelled ICP-MS data, whereas the curved red line represents a comparison between the ICP-OES data and levelled ICP-MS data. The solid red and blue lines represent the linear regression trend lines. Each data point (shown as a blue or red square) corresponds to a standard value, as listed in Table 5, below.

Table 5. Levelling Step 2: Levelling ICP-MS Zn data with ICP-OES Zn data.

	Zn (ppm) Actlabs® ICP-OES	Zn (ppm) ACME® ICP-MS	Correction Factor: ICP-OES = (ICP-MS + 8) x 1.06
No.	8 standards	8 standards	
Minimum	55	40	
Maximum	3275	3358.5	
Mean	482.6	481.4	
TILL-3	55	40	50.88
TILL-4	64	59.2	71.23
NB-CS1	81	67.3	79.82
TILL-1	83.5	65.43	77.84
STSD-4	86	78.1	91.27
NB-02	96	76	89.04
TILL-2	120	106.8	121.69
NB-01	3275	3358.5	3568.49

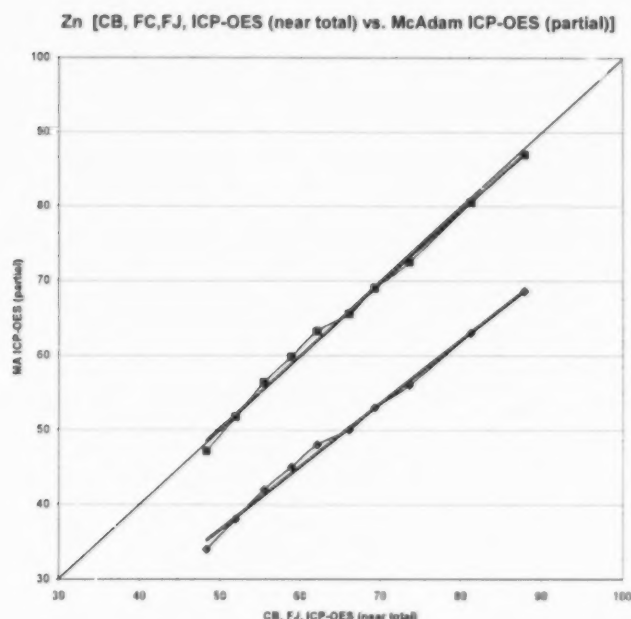


Figure 17. Zn x-y plot used to aid in levelling ICP-OES data from the McAdam (MA) survey with ICP-OES data from the adjacent Canterbury (CB) Forest City (FC), and Fredericton Junction (FJ) surveys. The curved blue line represents the contrast in the CB, FC, and FJ ICP-OES data and unlevelled MA ICP-MS data, whereas the red line represents a comparison between the CB, FC, and FJ ICP-OES data and levelled MA ICP-MS data. The solid blue and red lines are linear regression trend lines. Each data point (shown as a blue or red square) corresponds to a percentile value. From left to right, they are the 10th, 20th, 30th ..., 90th, and 95th percentiles, as listed in Table 6, below.

Table 6. Levelling Step 3: Levelling Zn concentrations in basal till from the McAdam survey with Zn concentrations in basal till from the Canterbury, Forest City, and Fredericton Junction surveys. * CB = Canterbury, FC = Forest City, FJ = Fredericton Junction, MA = McAdam.

	Zn (ppm) (ICP-OES + AAS) and ICP-MS for CB, FC, FJ *	Zn (ppm) (ICP-OES + AAS) and ICP-MS for MA *	Correction Factor: MA = [(CB, FC, FJ) * + 7] x 1.15
No.	443	229	
Minimum	33.88	16.00	
Maximum	152.79	80.00	
Mean	64.13	47.77	
10th %ile	48.30	34.00	47.15
20th	51.93	38.00	51.75
30th	55.50	42.00	56.35
40th	58.90	45.00	59.80
50th	62.12	48.00	63.25
60th	66.12	50.00	65.55
70th	69.30	53.00	69.00
80th	73.65	56.00	72.45
90th	81.29	63.00	80.50
95th	87.93	68.60	86.94

survey. As noted earlier, the base-metal values of the McAdam map area were anomalously low when compared with those of surrounding map areas. This was determined to have resulted from a change in detection parameters and/or digestion conditions inherent to that particular survey. Zn concentrations in till from the McAdam area do not appear to accurately measure the geochemical relief, when compared with Zn values obtained from the surrounding map areas. For this reason, quantile regression levelling was applied to the data.

Combined data from the Canterbury (21 G/14), Forest City (21 G/12), and Fredericton Junction (21 G/10) map areas were selected as the "reference" to which the McAdam survey was levelled. The combination was considered a suitable reference data set for the McAdam survey, based on the fact that all three map areas lay geographically adjacent to the McAdam map area, had similar underlying bedrock, and showed similar geochemical concentrations in the background-to-threshold anomalous range. Table 6 shows the discrepancy in Zn concentration between the data sets, and Figure 17 shows their linear relationship. A shift correction and slight multiplier correction was sufficient to level the data sets.

$$\text{Zn ppm: MA ICP-OES values} = [(\text{CB, FC, and FJ ICP-OES values}) + 7] \times 1.15$$

where MA = McAdam survey, CB = Canterbury survey,
FC = Forest City survey, and FJ = Fredericton Junction survey

For comparative purposes, two Zn contour maps are presented here. Figure 18 shows the contour map before levelling, and Figure 19 shows the contour map as levelled to ICP-OES. Data were converted to percentiles before contouring. The geological base map is an excerpt from Map NR-1, *Bedrock Geology of New Brunswick* (NBDNRE 2000).

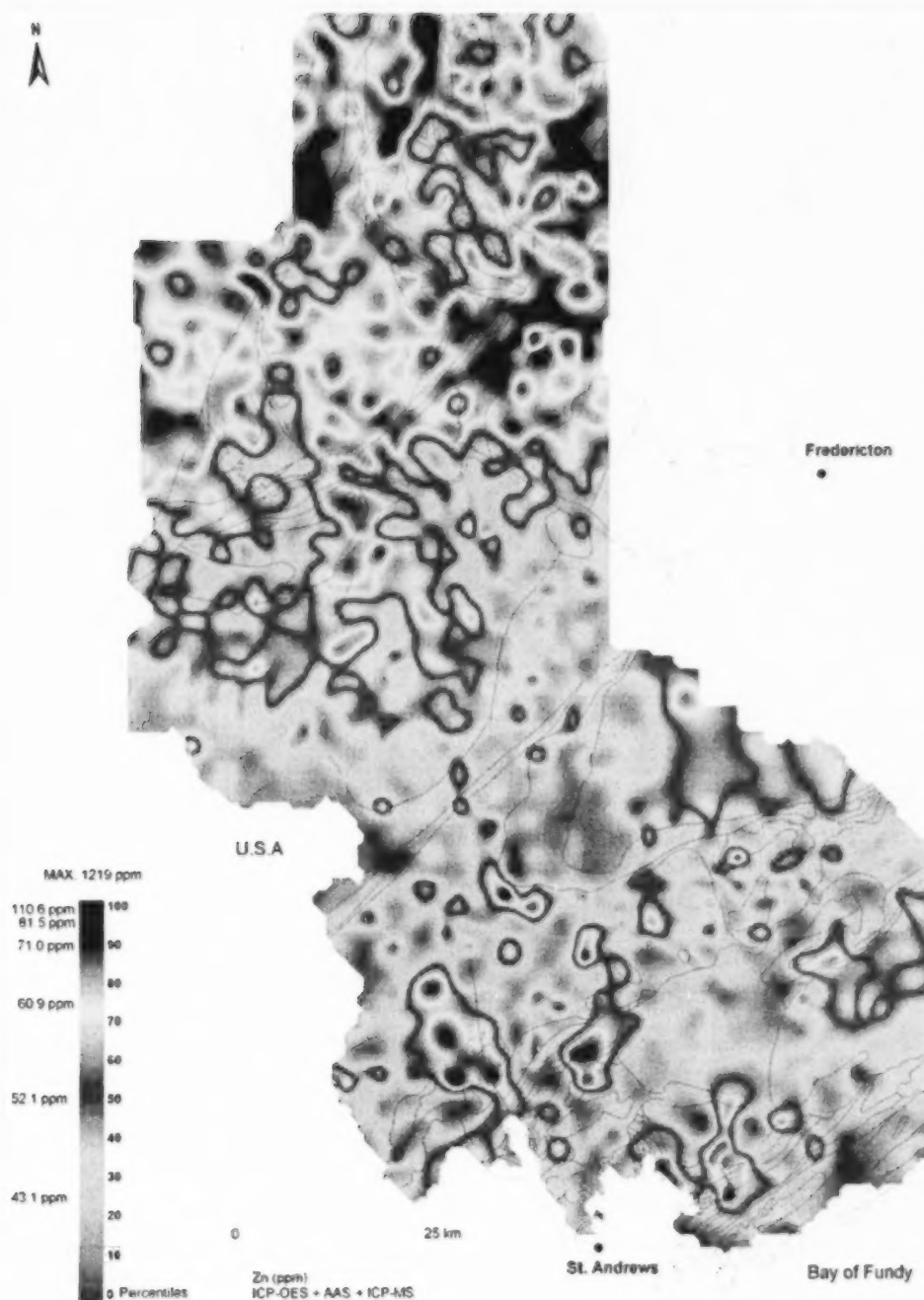


Figure 18. Unlevelled Zn contour map. Data represent the combination of ICP-OES, AAS, and ICP-MS analytical techniques. Geological base map is an excerpt of Map NR-1 (NBDNRE 2000).

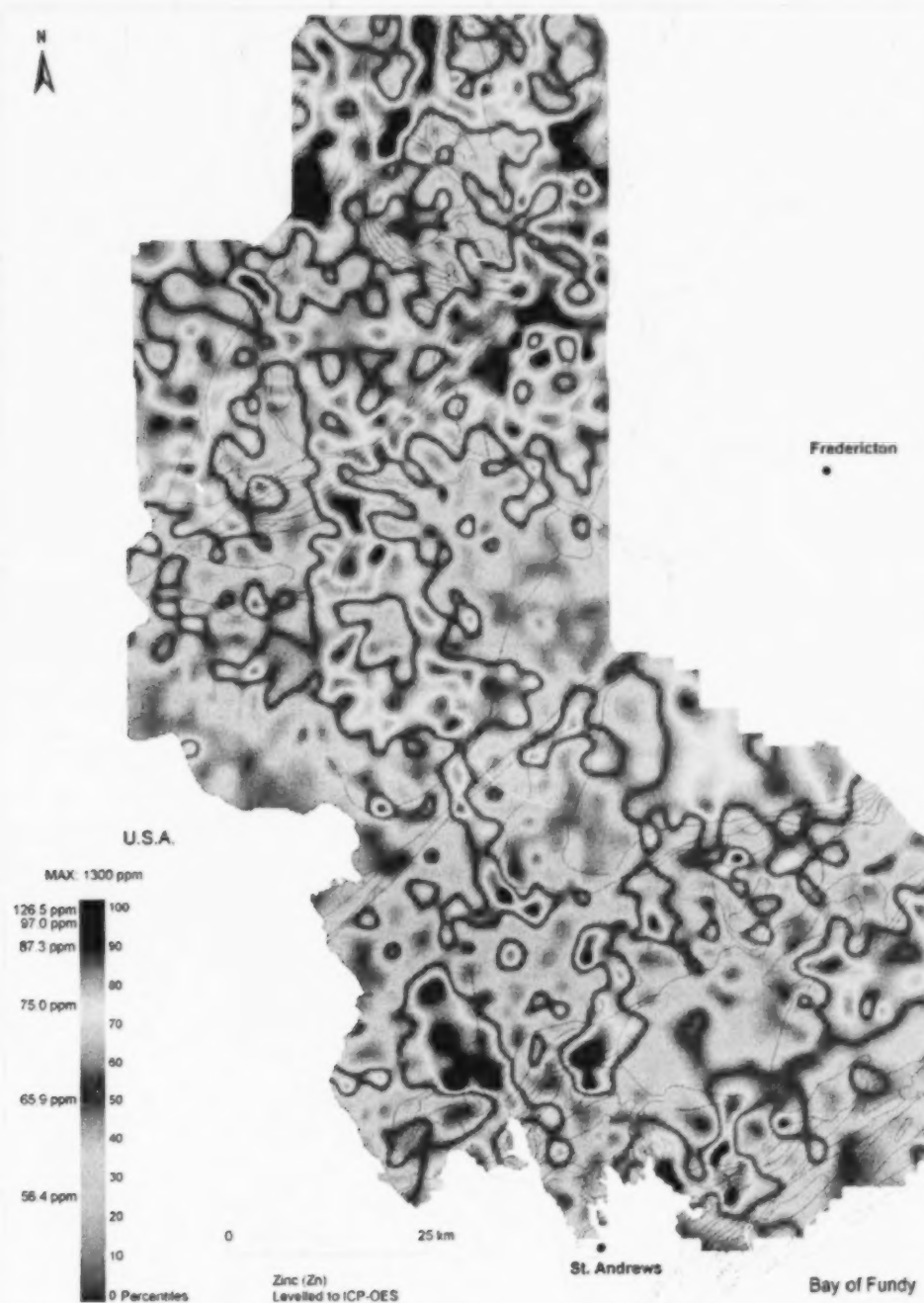


Figure 19. Zn contour map, levelled to ICP-OES. Data represent the combination of ICP-OES, AAS, and ICP-MS analytical techniques. Geological base map is an excerpt of Map NR-1 (NBDNRE 2000).

APPENDIX 2. VARIOGRAM PARAMETERS

The variance structure of the geochemical data was modelled using Surfer® 8 according to parameters described in Table 7, below.

Table 7. Variogram parameters used for the kriging algorithm during the contouring process.

Component	Model Type	Scale (m)	Length (m)	Anisotropy Ratio	Anisotropy Angle (°)
As	Exponential	1000	18000	1.3:1	13.2
Ba	Exponential	803.8	3923	1.3:1	99.03
Co	Exponential	800	8000	1.3:1	50
Cr	Exponential	796.9	10620	1.296:1	101.3
Cs	Exponential	1134	33580	2:1	116.9
Cu	Exponential	768.9	7978	1.2:1	44.7
Fe	Exponential	800	12000	1.2:1	21.7
Hg	Exponential	800	2232	1.183:1	133.7
Mn	Exponential	776.3	4069	1.2:1	61.46
Mo	Exponential	1389	7358	1.6:1	172.4
Ni	Exponential	700	10000	1.1:1	67.45
Pb	Exponential	740.3	9670	1.099:1	90
Rb	Exponential	783.3	5522	1.6:1	99.04
Sb	Exponential	916.3	10560	1.6:1	118.2
Th	Quadratic	873.1	48360	1.745:1	90
U	Exponential	890	14000	1.3:1	78.52
W	Exponential	1329	2039	1.27:1	110.4
Zn	Exponential	803.3	3289	1.288:1	109.2
BM *	Exponential	797.4	5793	1.158:1	19.98
NCC *	Exponential	751.4	9469	1.5:1	45.24
PM *	Exponential	843.7	2847	1.649:1	110.6
REE *	Exponential	826.4	6529	1.36:1	121.4
RM *	Exponential	842.6	9691	1.626:1	104.3
Sn-W *	Exponential	793.8	6879	1.545	96.92

* **BM** = base-metal-mineralization indicator (combined plot of normalized Cu, Pb, Zn, Mn, As, Sb, and Au concentrations in till). **NCC** = nickel-cobalt-copper-mineralization indicator (combined plot of normalized Ni, Co, Cu, and Cr concentrations in till). **PM** = precious-metal-mineralization indicator (combined plot of normalized Au, Ag, Sb, As, Hg, Th, and U concentrations in till). **REE** = rare-earth-element concentrations (combined plot of normalized Ce, Eu, La, Lu, Sm, Tb, and Yb in till). **RM** = rare-metal-mineralization indicator (combined plot of normalized Cs, Rb, U, Th, Ce, Eu, La, Sm, Tb, and Yb concentrations in till). **Sn-W** = tin-tungsten-mineralization indicator (combined plot of normalized W, Mo, Cu, Rb, and Cs concentrations in till).

APPENDIX 3. SINGLE-ELEMENT CONTOUR MAPS AND MULTIVARIATE RARE-EARTH-ELEMENT INDICATOR MAP

The 18 levelled, single-element contour maps in this report show concentrations for As (Fig. 20), Ba (Fig. 21), Co (Fig. 22), Cr (Fig. 23), Cs (Fig. 24), Cu (Fig. 25), Fe (Fig. 26), Hg (Fig. 27), Mn (Fig. 28), Mo (Fig. 29), Ni (Fig. 30), Pb (Fig. 31), Rb (Fig. 32), Sb (Fig. 33), Th (Fig. 34), U (Fig. 35), W (Fig. 36), and Zn (Fig. 37). Figure 38 represents a multivariate rare-earth-element (Ce, Eu, La, Lu, Sm, Tb, and Yb) indicator map.

Data for the above-listed elements were levelled to represent Actlabs® INAA values, except for Cu, Mn, Ni, Pb, and Zn, which were levelled to represent Actlabs® ICP-OES (four-acid digestion) values. *Contouring Methods* in this report explains contouring methods used to obtain the data; *Data Set Properties and Levelling Scenarios* provides an overview of the current till geochemical data set; and *Appendix 1* explains the levelling methods used.

The maps are presented here as page-sized colour contour plots with an underlay of bedrock geology derived from Map NR-1, *Bedrock Geology of New Brunswick* (NBDNRE 2000). Figure 6 provides an overview of bedrock geology in the report area and is excerpted from Map NR-1.

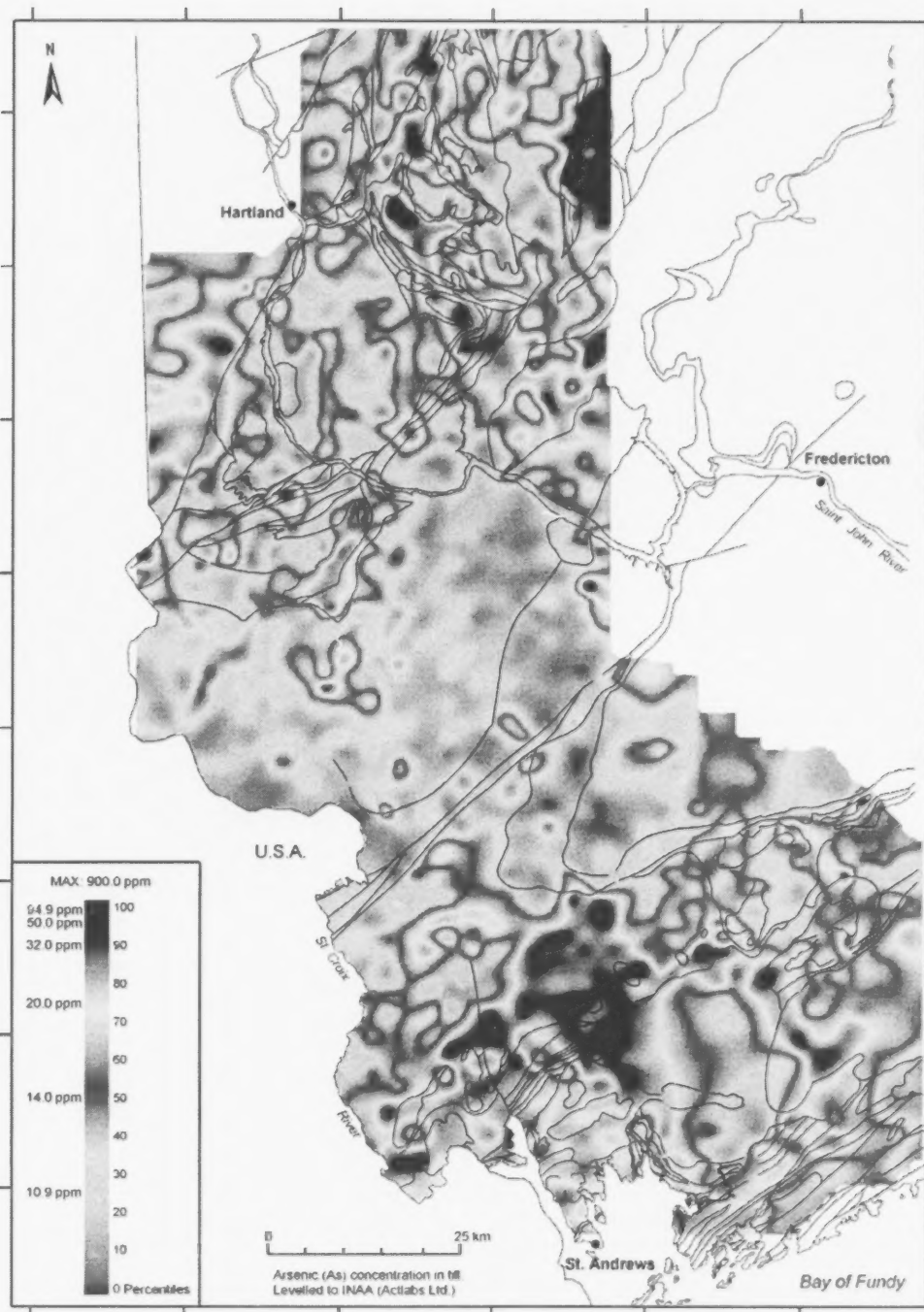


Figure 20. As concentration in basal till (< 63 µm fraction).

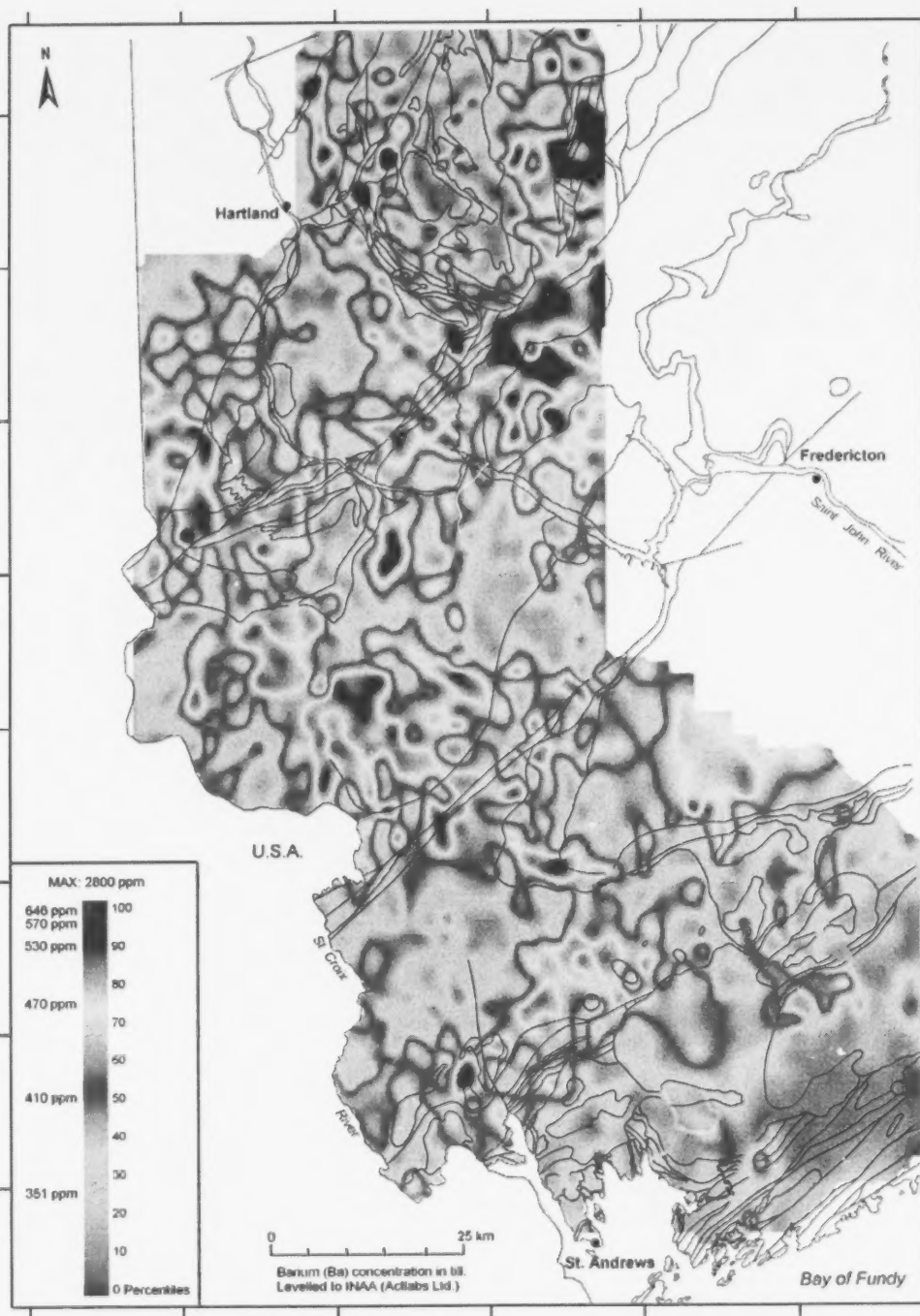


Figure 21. Ba concentration in basal till (< 63 μm fraction).

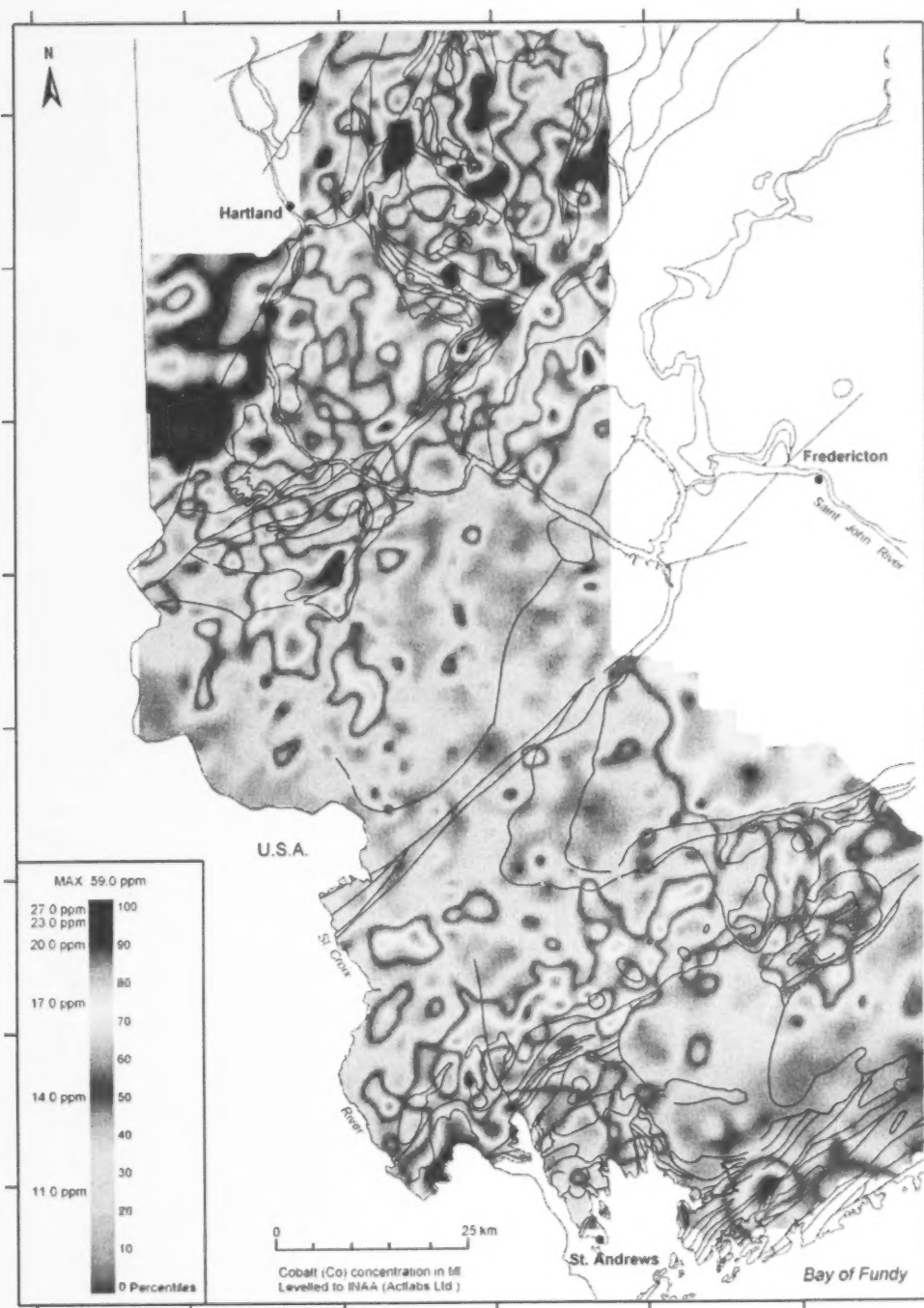


Figure 22. Co concentration in basal till (< 63 µm fraction).

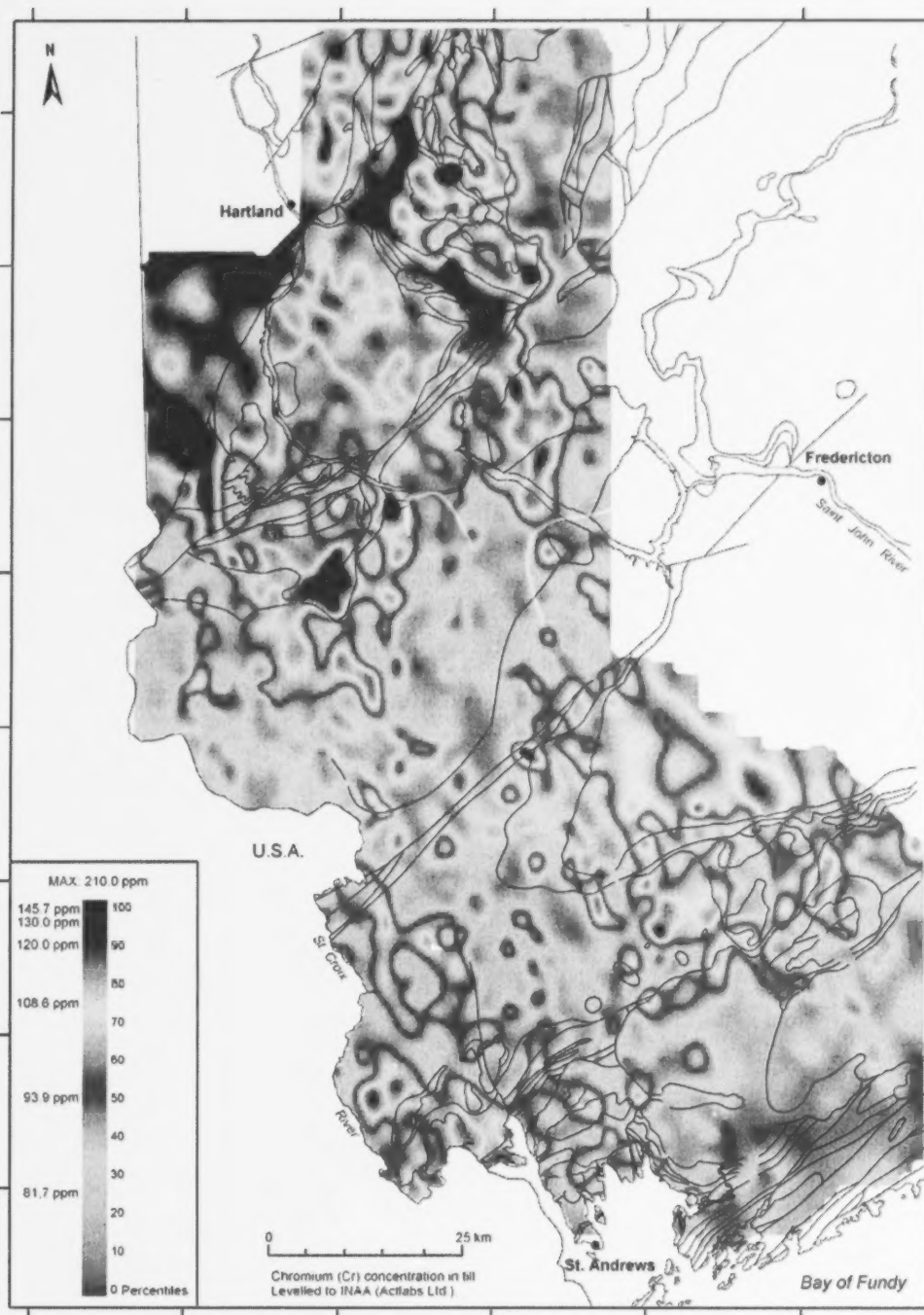


Figure 23. Cr concentration in basal till (< 63 μm fraction).

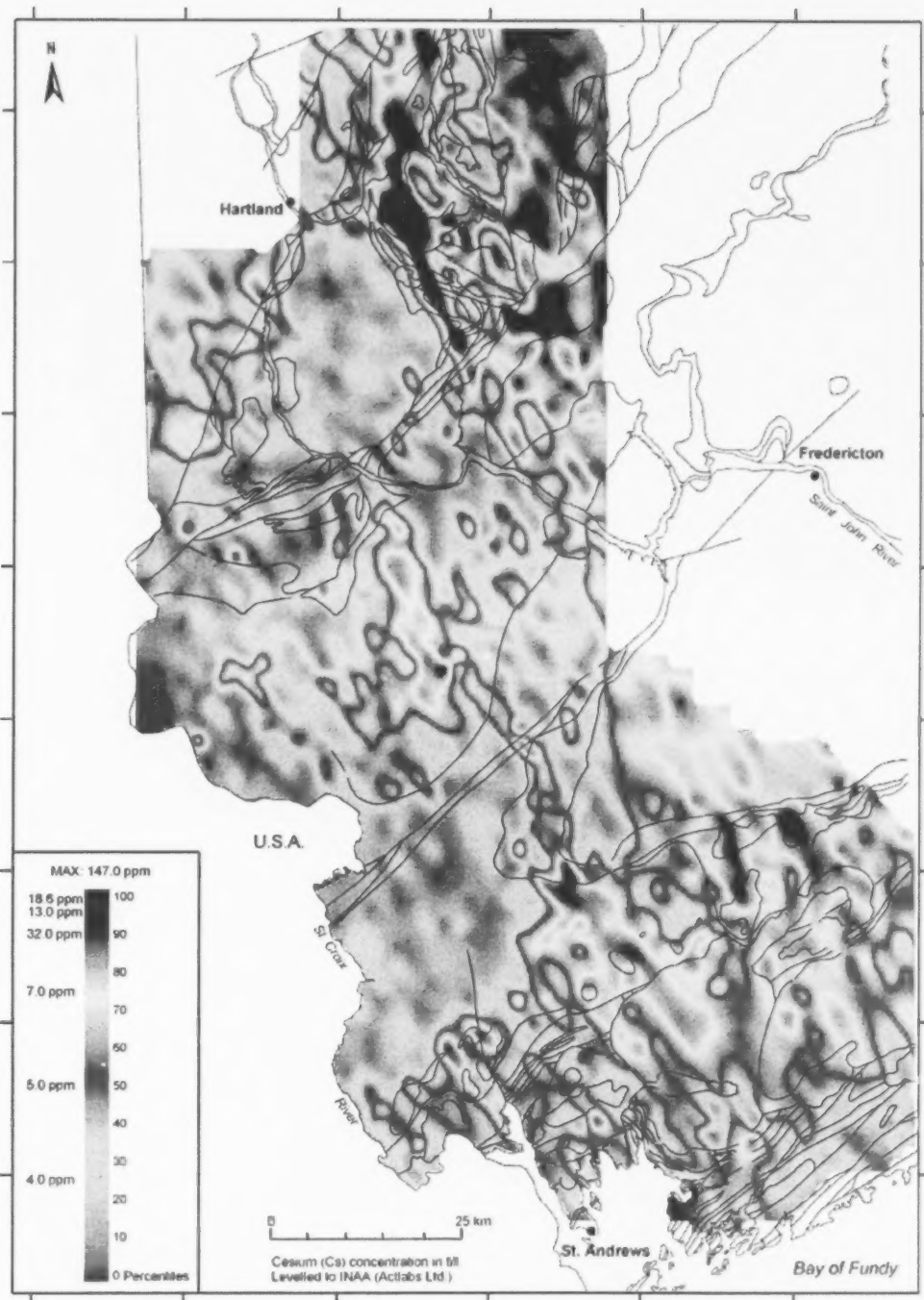


Figure 24. Cs concentration in basal till (< 63 µm fraction).

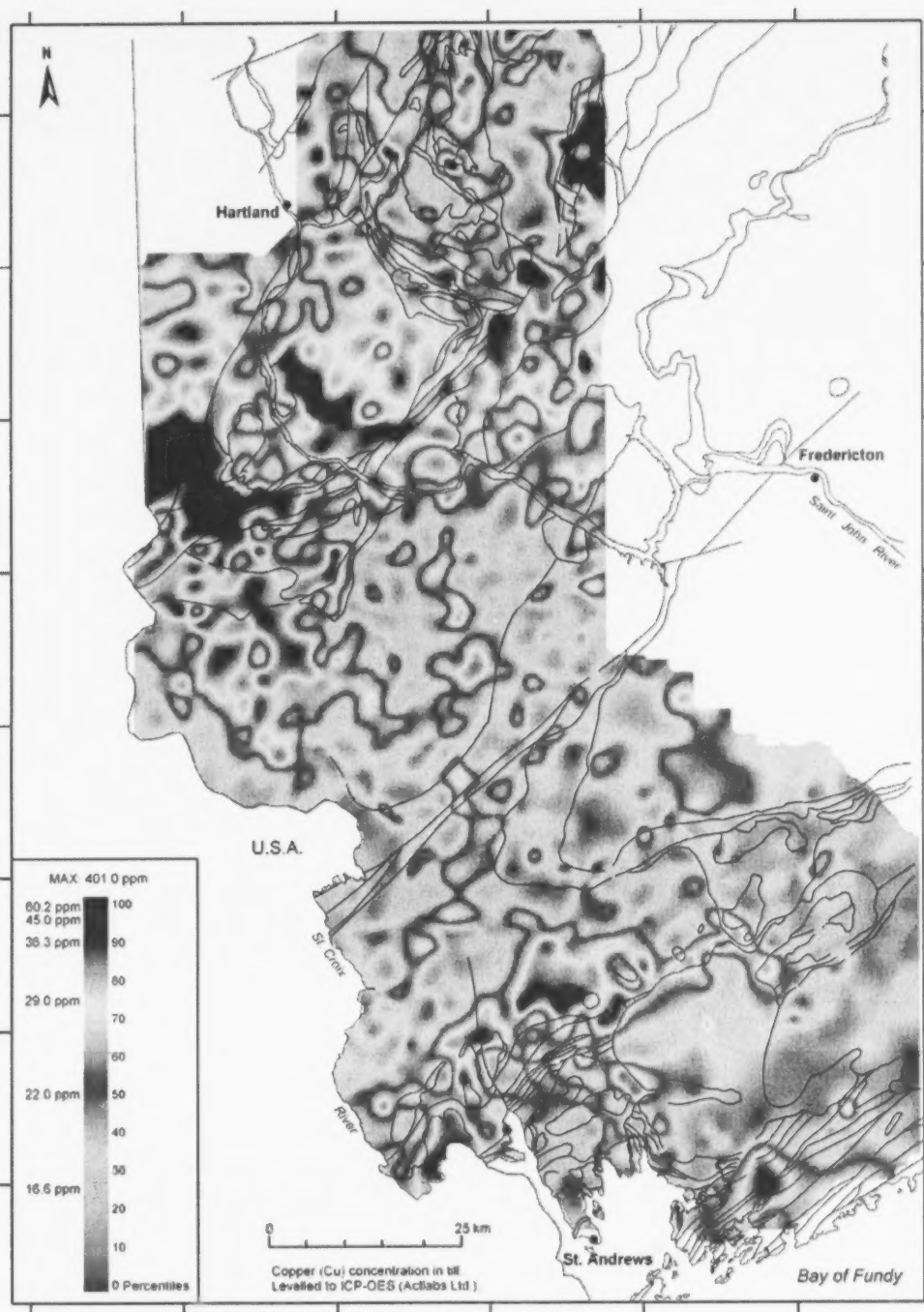


Figure 25. Cu concentration in basal till (< 63 µm fraction).

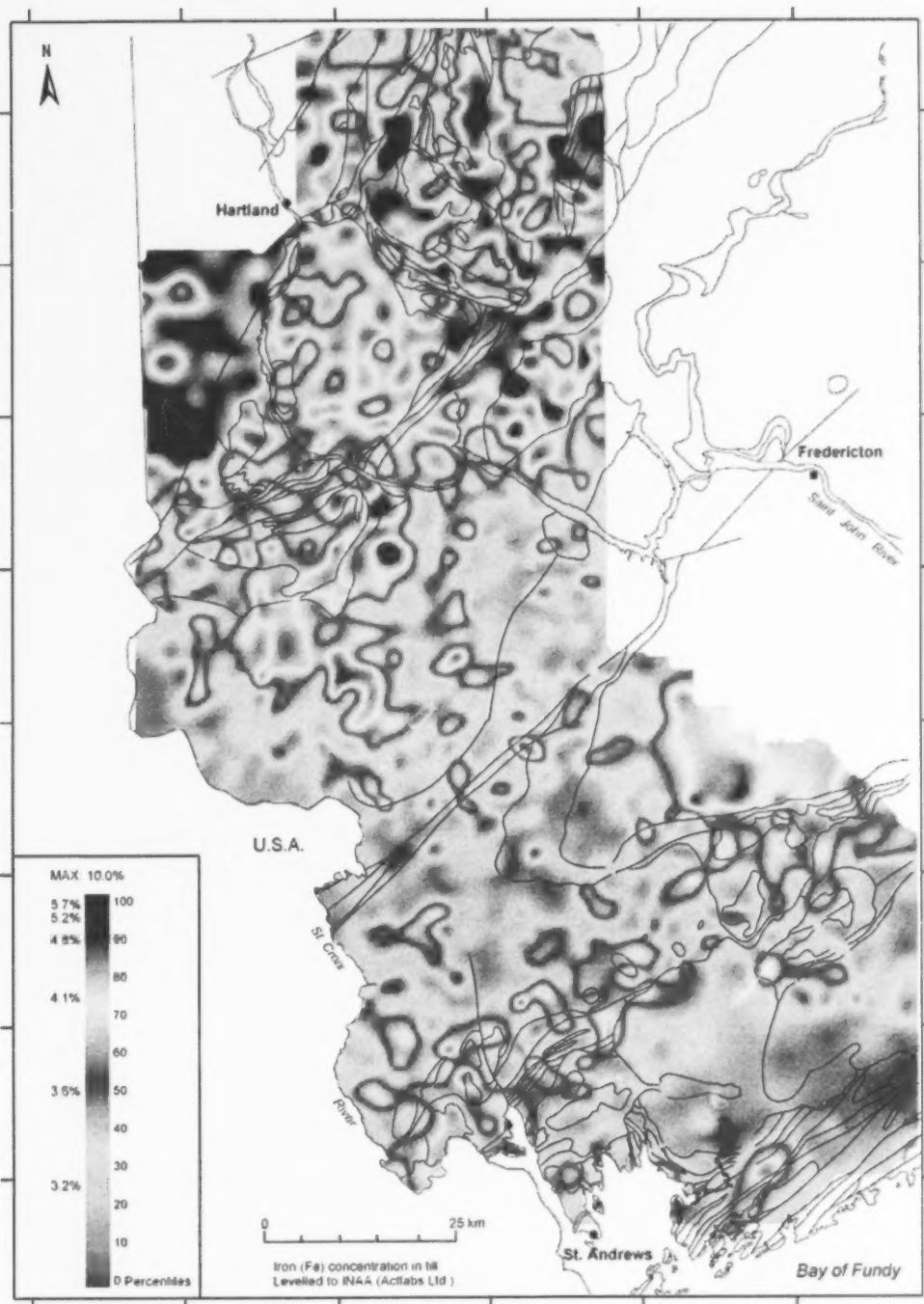


Figure 26. Fe concentration in basal till (< 63 µm fraction).

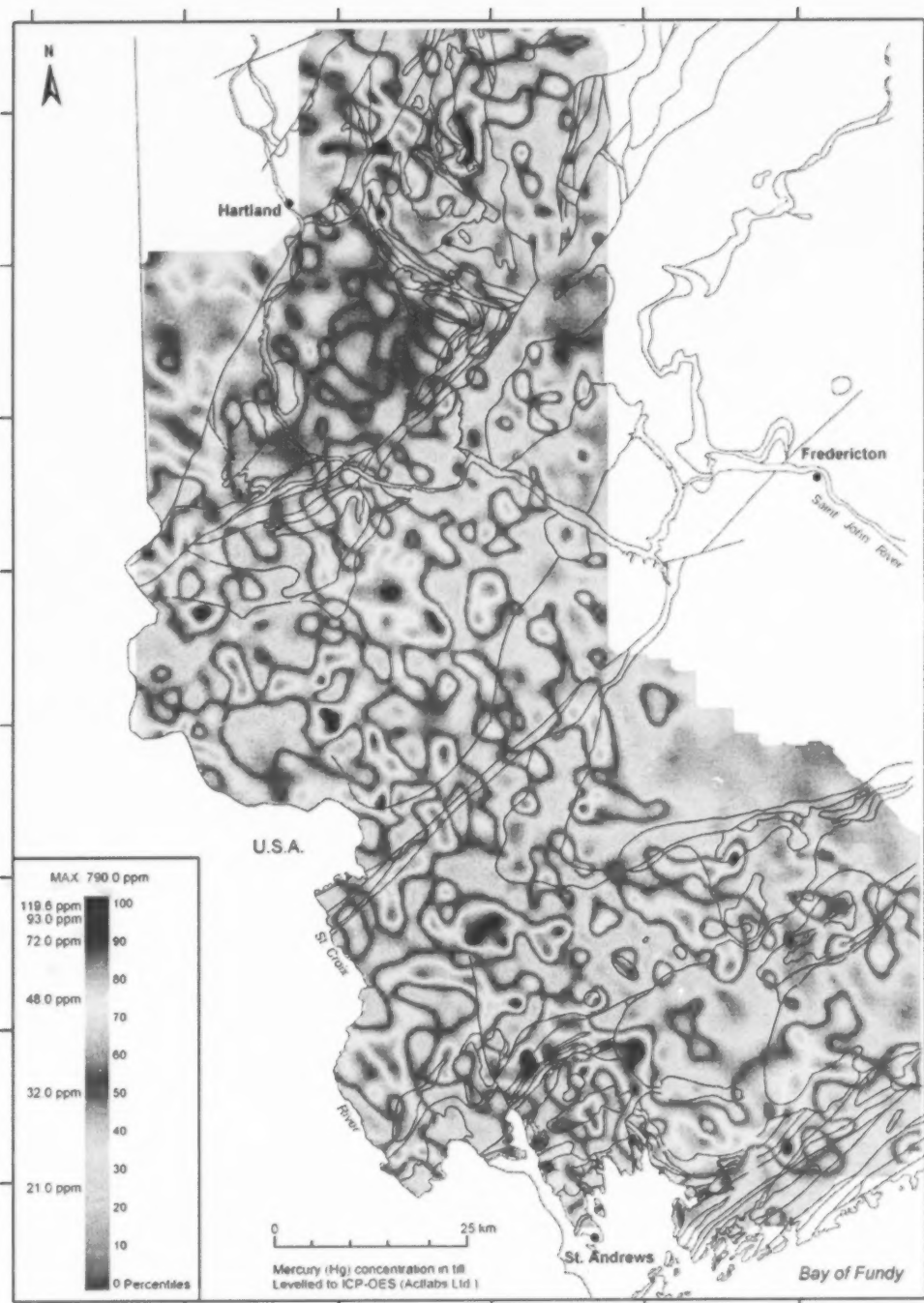


Figure 27. Hg concentration in basal till (< 63 µm fraction).

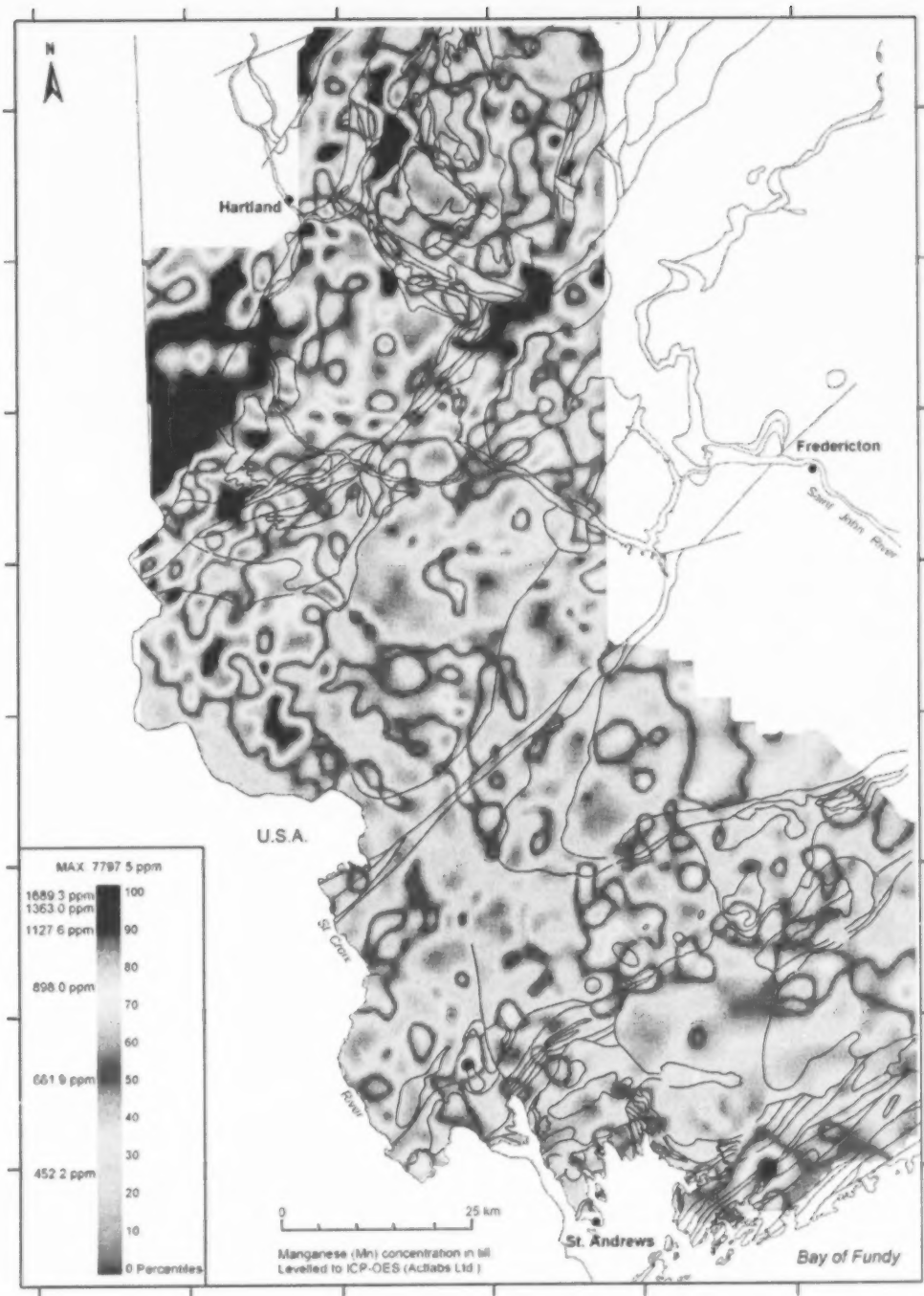


Figure 28. Mn concentration in basal till (< 63 µm fraction).

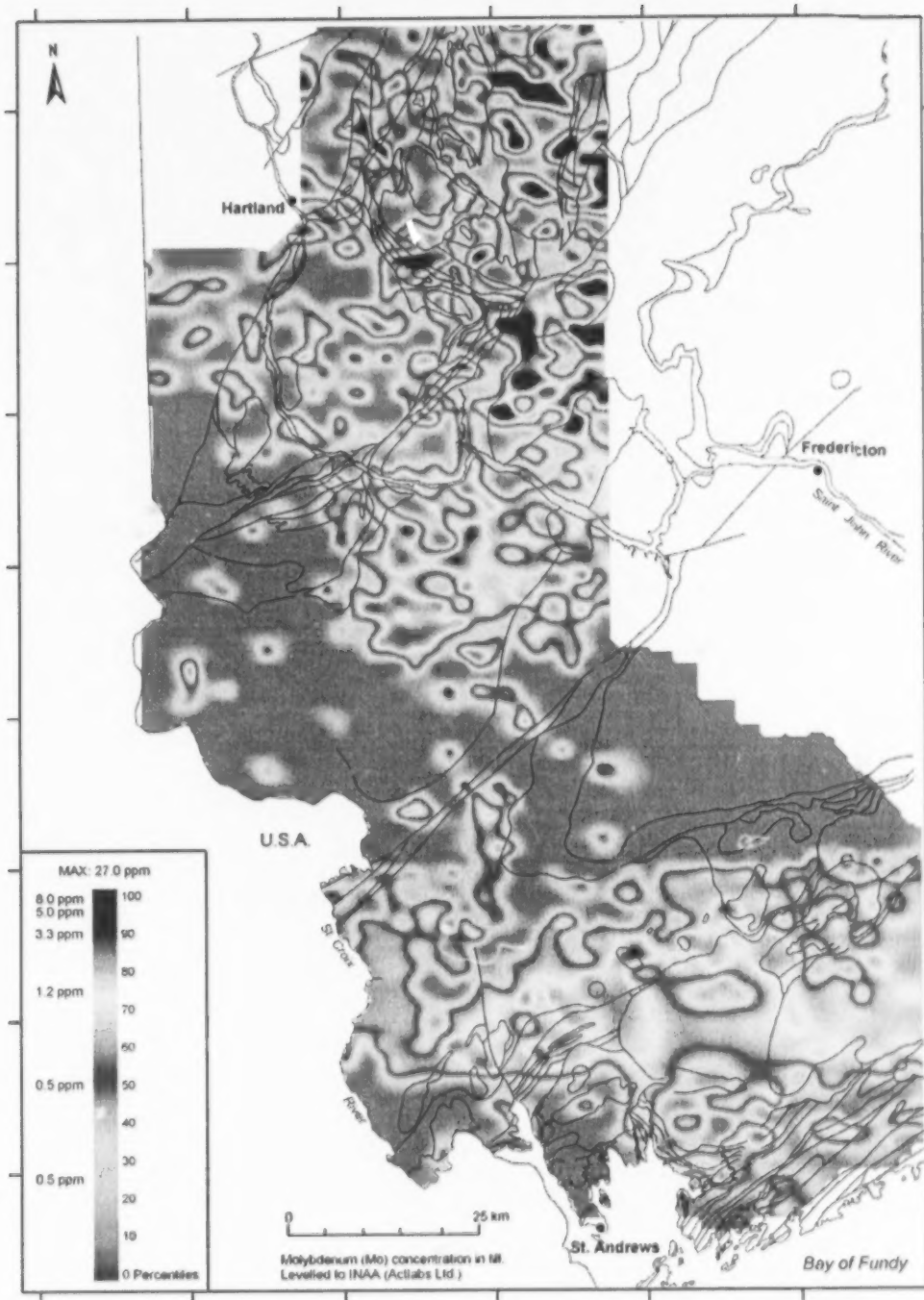


Figure 29. Mo concentration in basal till (< 63 μ m fraction).

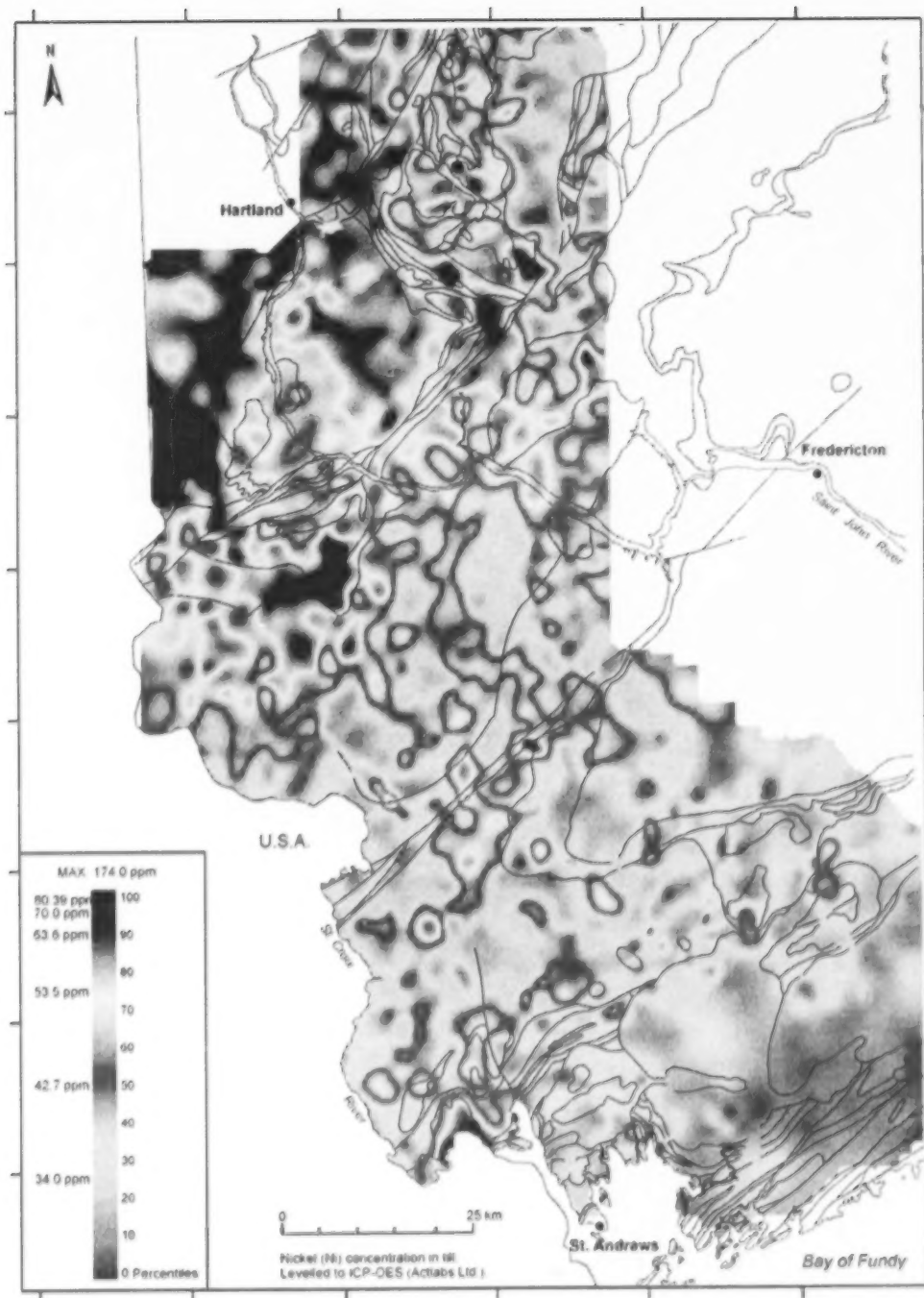


Figure 30. Ni concentration in basal till (< 63 μm fraction).

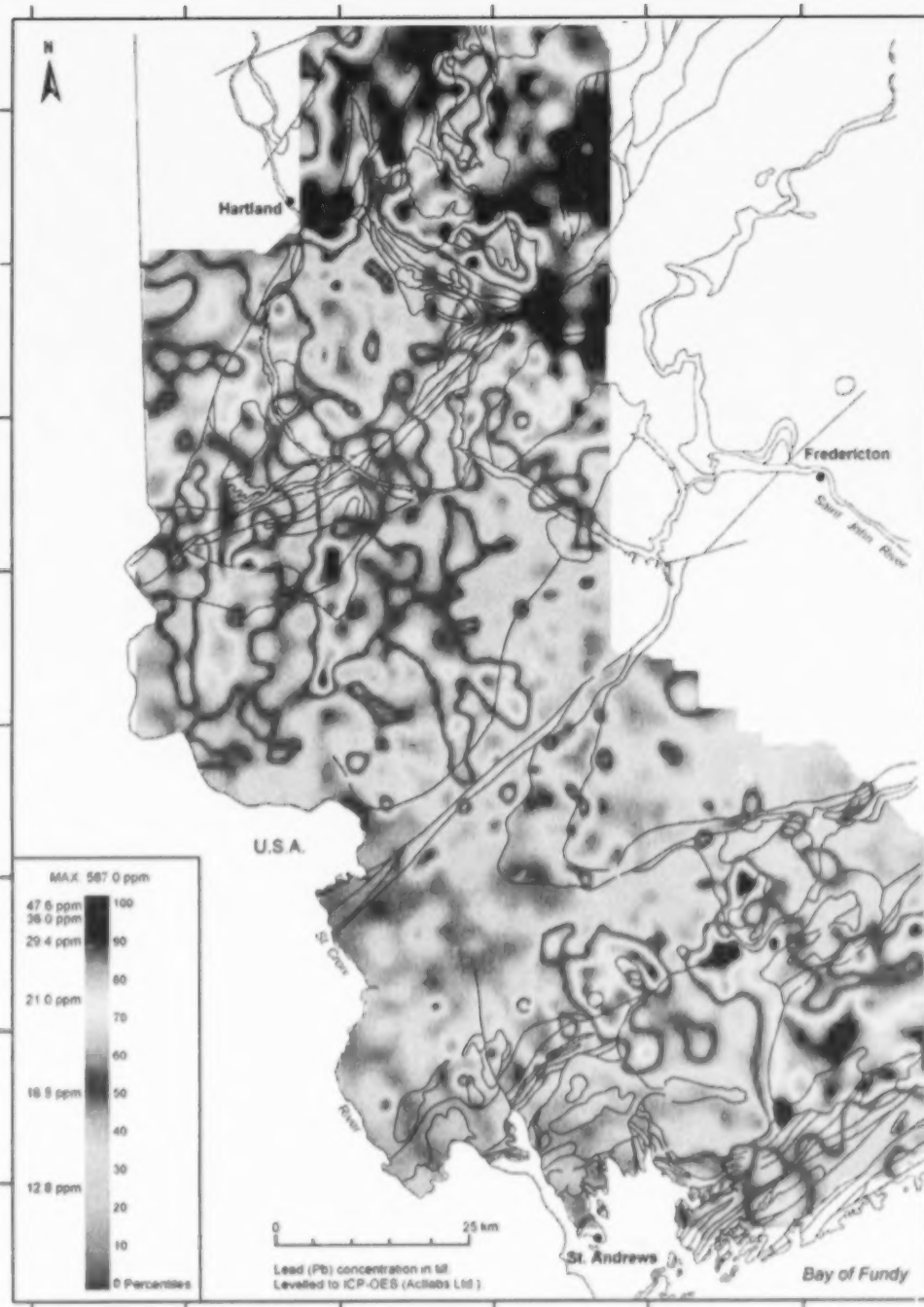


Figure 31. Pb concentration in basal till (< 63 μm fraction).

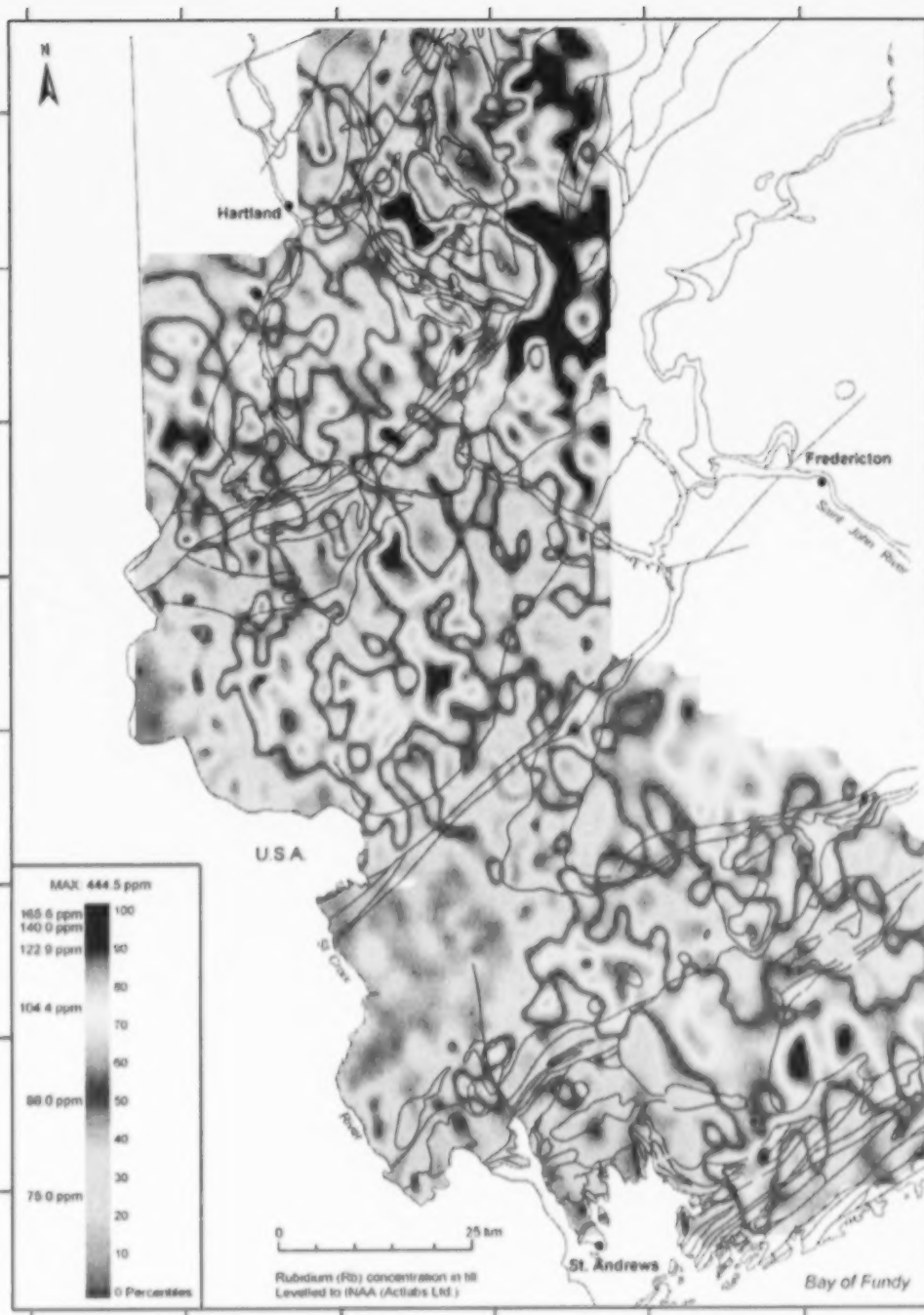


Figure 32. Rb concentration in basal till (< 63 µm fraction).

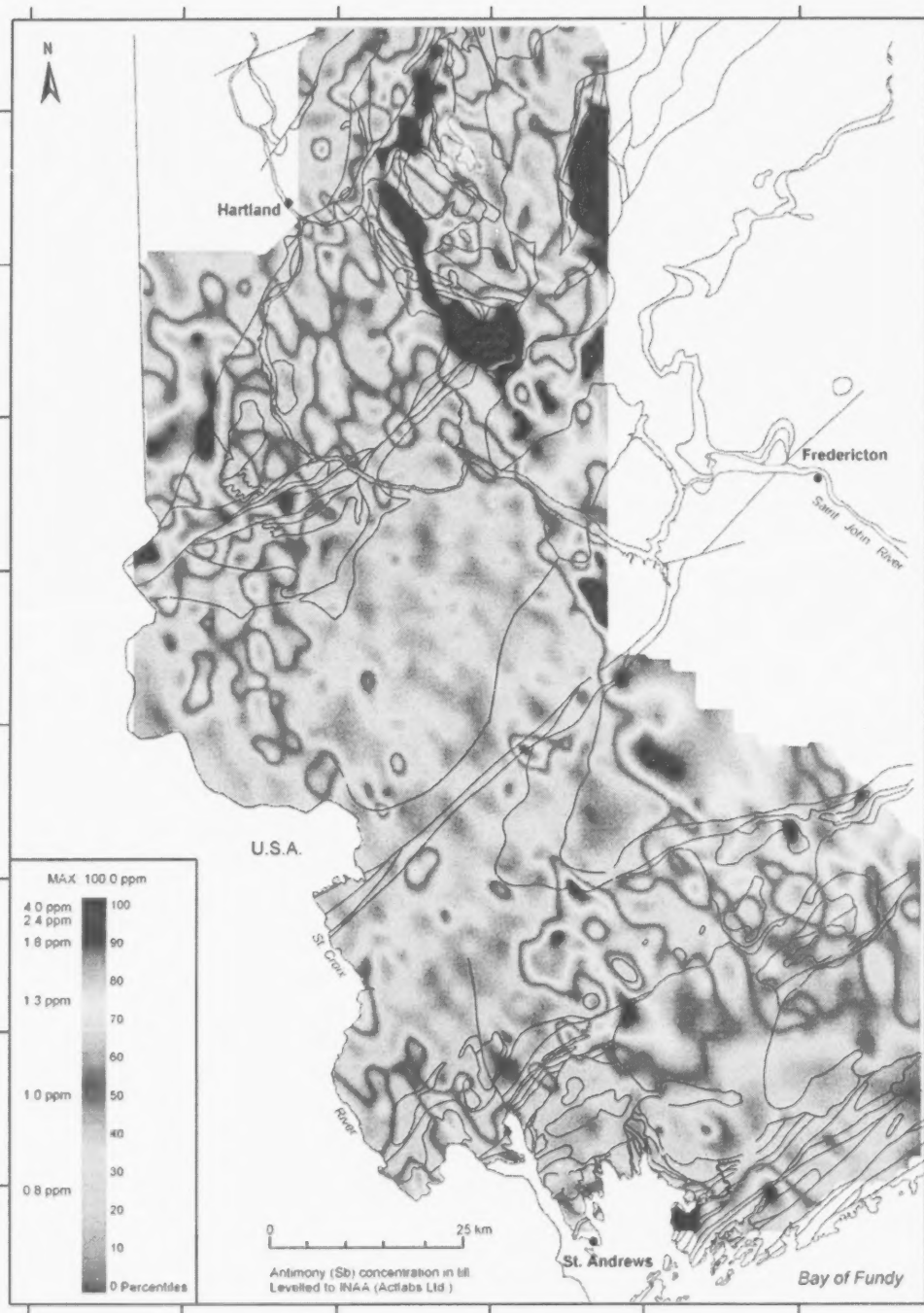


Figure 33. Sb concentration in basal till (< 63 µm fraction).

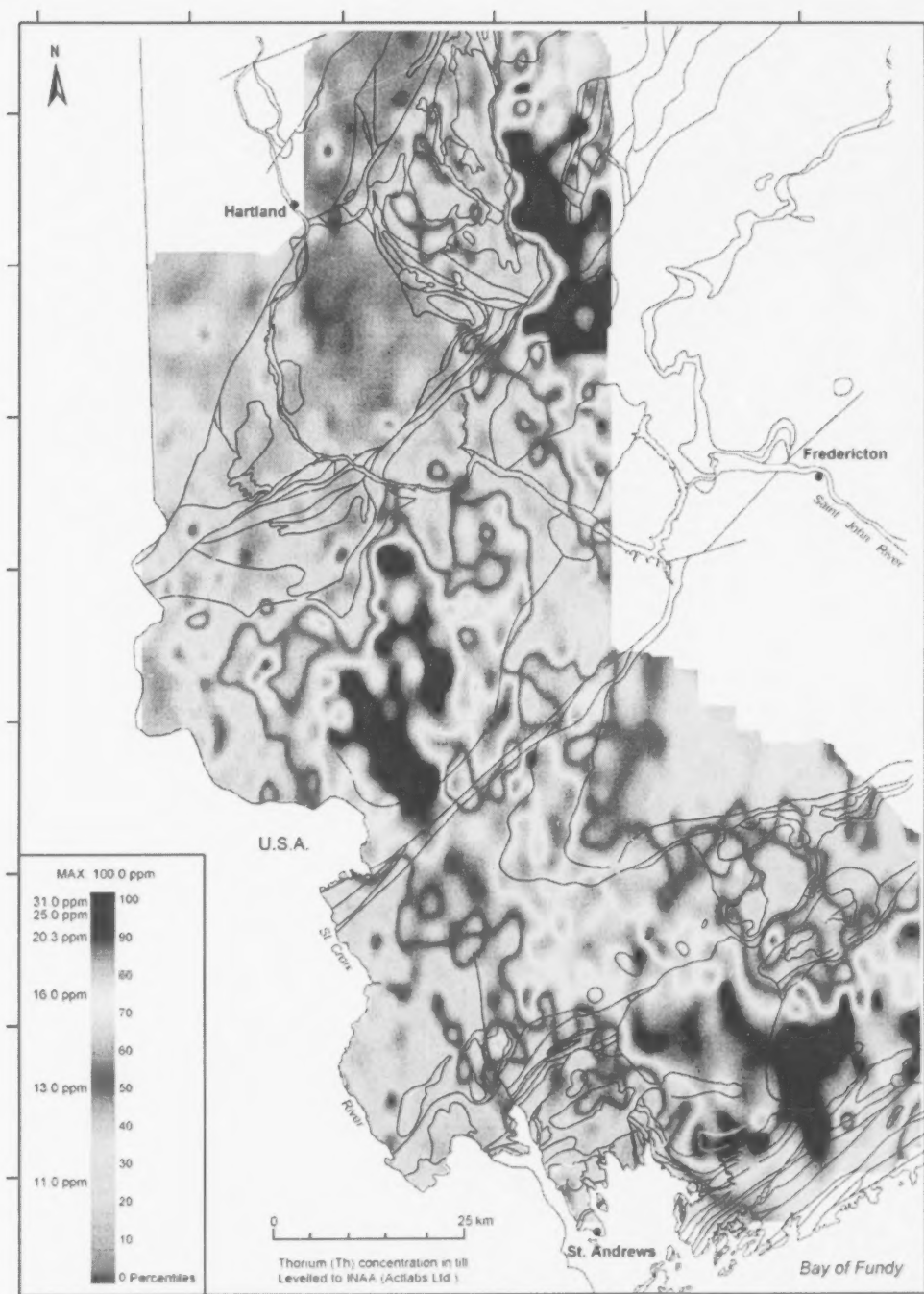


Figure 34. Th concentration in basal till (< 63 μm fraction).

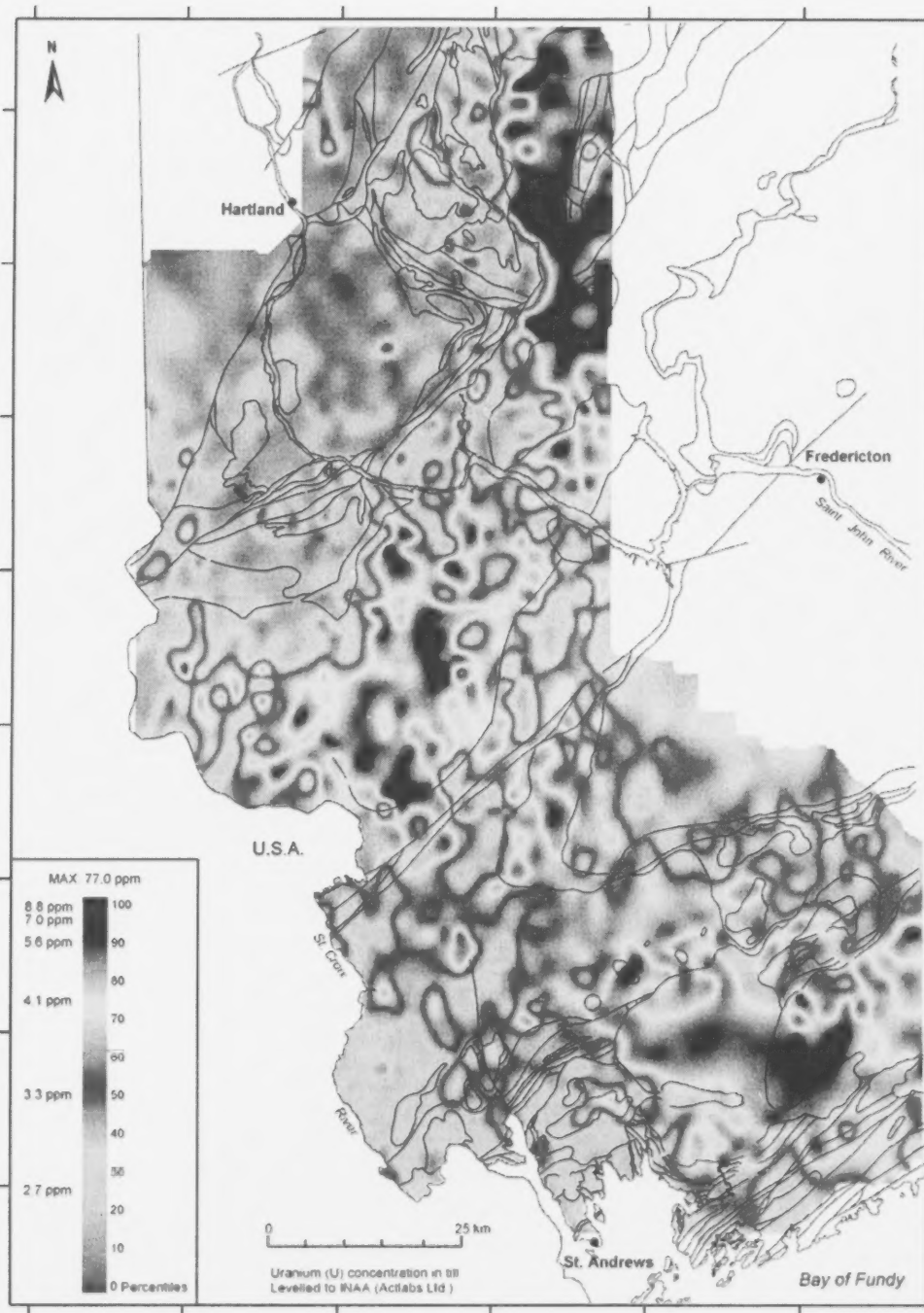


Figure 35. U concentration in basal till (< 63 μm fraction).

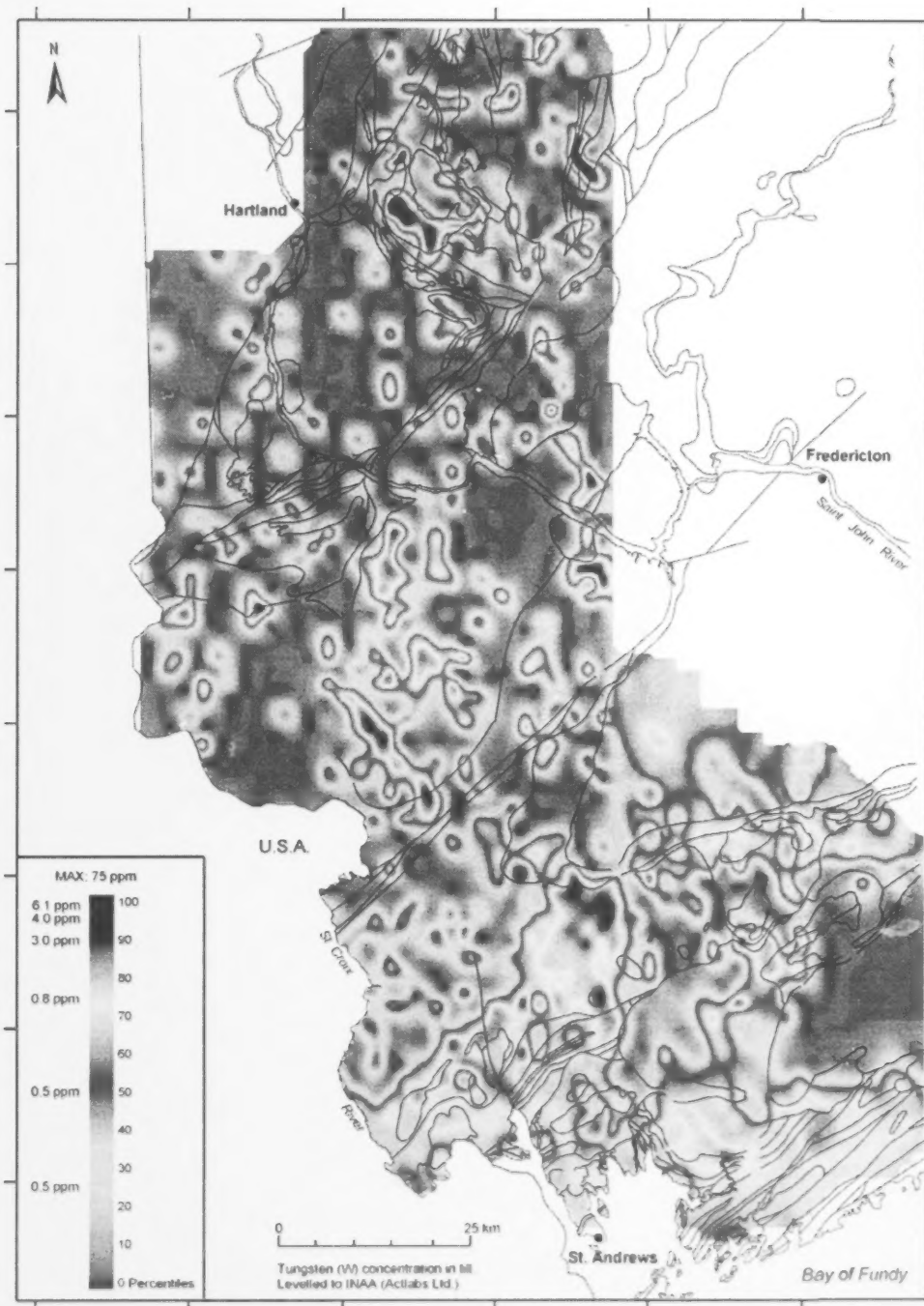


Figure 36. W concentration in basal till (< 63 µm fraction).

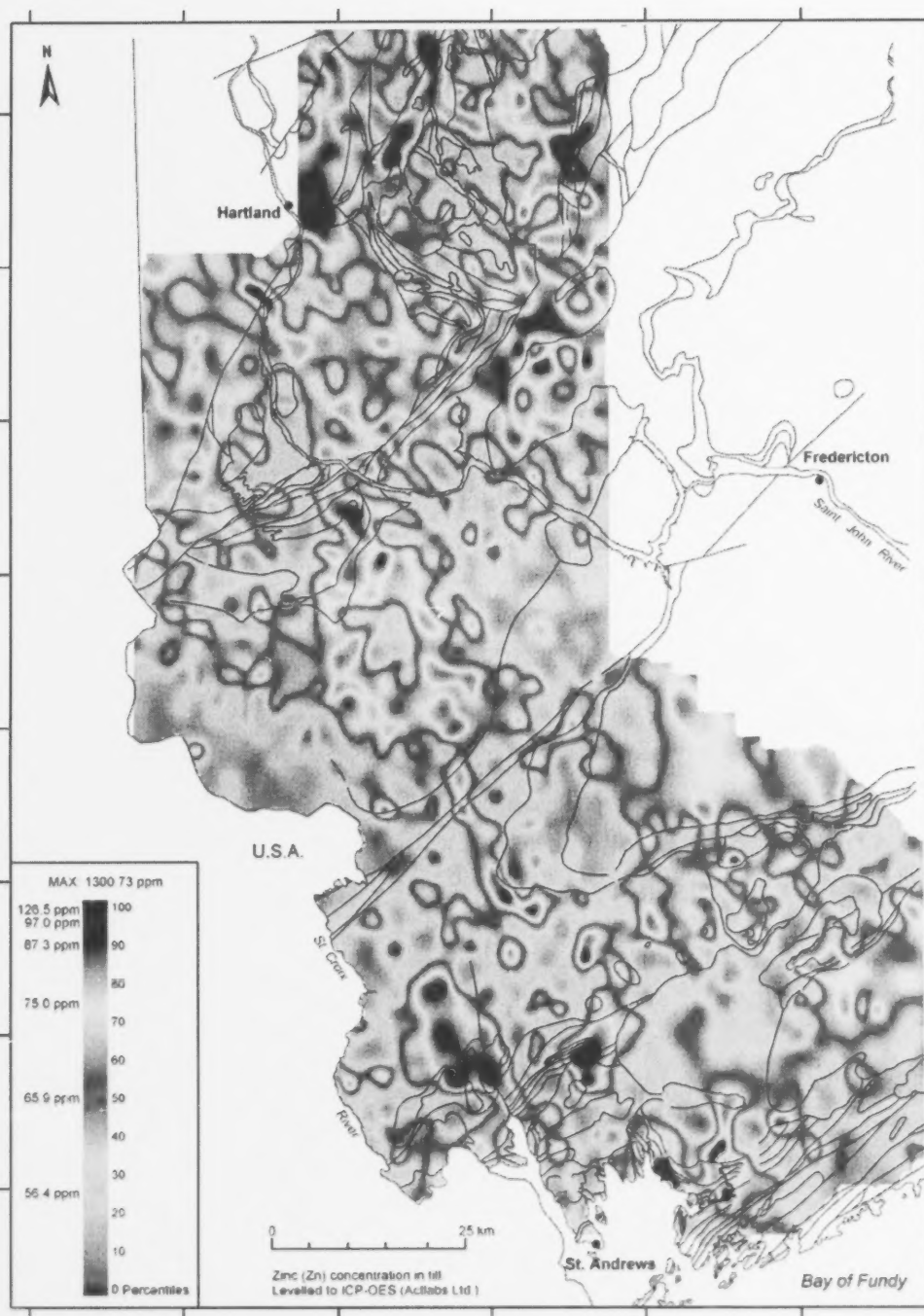


Figure 37. Zn concentration in basal till (< 63 μm fraction).

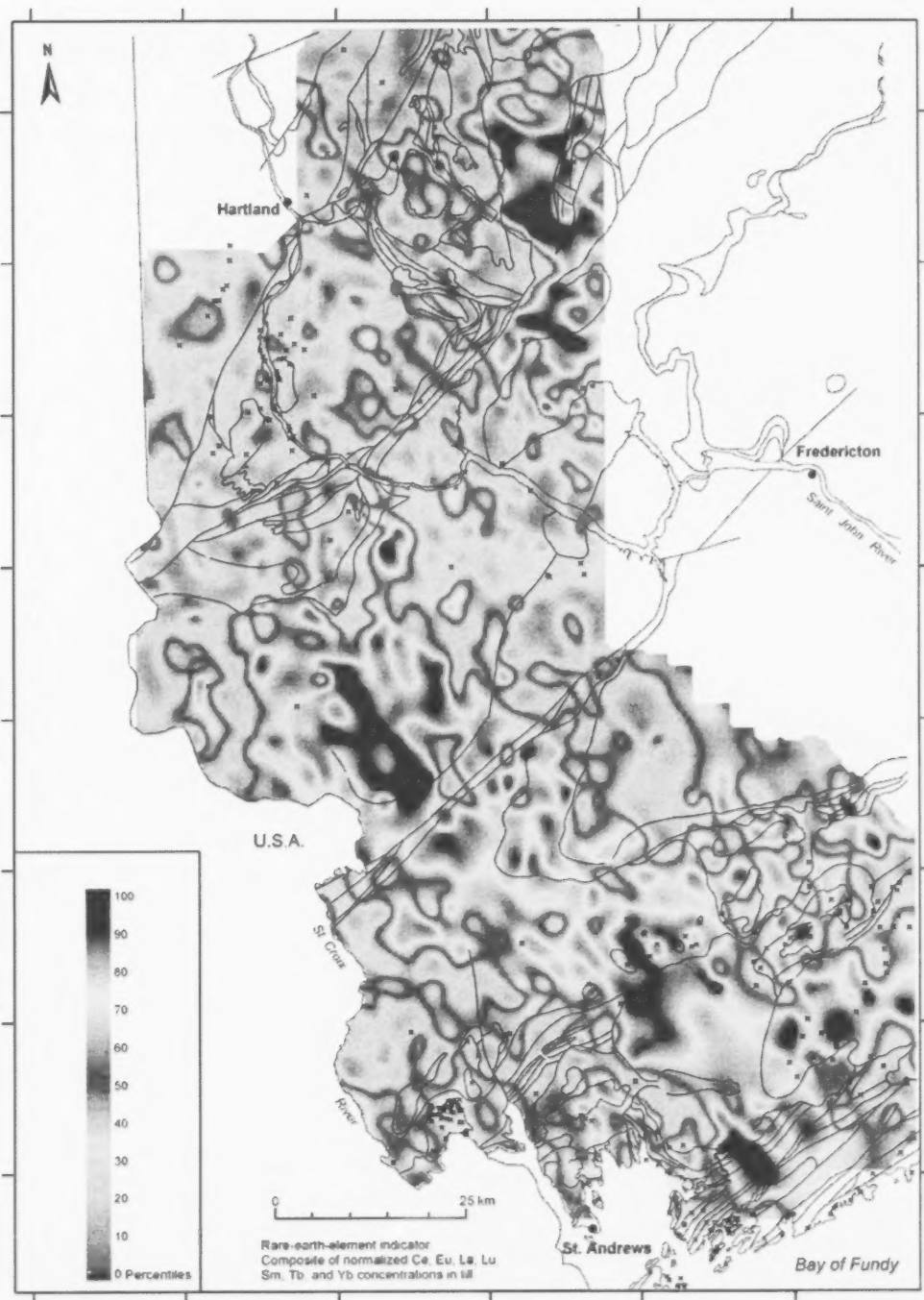


Figure 38. Multivariate rare-earth-element indicator in basal till (< 63 μ m fraction).

